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DOCUMENTATION OF THE 1984 DOMOINA FLOODS

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Page 10, 8th line from top	cross-latitude	cross latitude
Page 24, Table 5.3: heading	$h\Delta$	h_s
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DEPARTMENT OF WATER AFFAIRS

Directorate of Hydrology

Technical Report TR 122

DOCUMENTATION OF THE 1984 DOMOINA FLOODS

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Cover: White Mfolozi River at the Ulundi-Melmoth road bridge during the domoina floods

(Photo: P. Berridge, KwaZulu Department of Agriculture and Forestry)

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CONTENTS

1. INTRODUCTION

On 27 January 1984, 10 days after she was first spotted on satellite photographs somewhere north of Mauritius in the Indian Ocean, tropical cyclone Domoina had reached the Mocambican coastline and moved into the African Continent (Photo 1). During the following five days torrential rains fell over Southern Mocambique, the Eastern Transvaal Lowveld, Swaziland and Northern Natal. The ensuing floods were, over large areas, the biggest ever remembered. Tens of thousands of people were directly affected and more than 200 persons died. In South Africa alone more than R100 million damage was caused to communications, agriculture and nature reserves. Less than three weeks after Domoina, on 18 February 1984 tropical cyclone Imboa reached the Zululand coast. Fortunately the cyclone changed course on the same day and moved away from the African Continent (Figure 2.1). The heavy rains were restricted to a narrow coastal strip between Cape St. Lucia and Durban causing only minor damage.

The Directorate of Hydrology of the Department of Water Affairs, following its well established practice of gathering relevant hydrological data on extraordinary floods, carried out an extensive field survey over the flood ravaged region (Figure 1.1). For the first time in Southern Africa the flood survey attained international character through an exchange of information between the three countries involved. Direct technical help was given by the Department to Swaziland for the execution of slope-area measurements in the Mlumati, Mkondvo and Great Usutu Rivers.

The basic information used for the hydrological documentation of the Domoina floods were rainfall data at more than 450 observation points (Appendix 1) and flood surveys or records at 85 sites in 45 rivers. Other useful information included daily synoptic weather charts, satellite photographs, colour LANDSAT images, aerial photographs, sediment samples, more than 200 flood questionnaire returns, photographs, Video-films, personal accounts by inhabitants, contact with scientists and experts and reports in the daily press and technical literature.

This technical report presents the results of hydrological and hydraulic calculations and analyses based on the above sources. It is intended primarily to serve as a data-source document for future flood investigations in the area. In compiling the documentation the main criterion has been to furnish the interested reader with a summary of relevant flood data for each of the 85 catchments. These comprise storm rainfall depth, flood peak with approximate return period and, whenever possible, also flood volume, run-off percentage and the time of flood peak (Appendix 2).

Cyclone Domoina has also focussed attention on a number of problems which are pertinent to a proper understanding and evaluation of extraordinary floods in the region. Such problems are, for example, the behaviour and frequency of tropical cyclones in the South West Indian Ocean, channel roughness, dam level disturbances by translatory waves, erosion and sediment problems in alluvial rivers, particularly in the Mfolozi River. These and a few other problems are also discussed in the report.

The report contains substantial photographic documentation and case studies of LANDSAT image interpretation.

Since tropical cyclone Imboa did not cause extraordinary floods, her documentation was limited to a storm isohyetal map and the listing of flood parameters at a few gauging stations in the Mhlatuze River catchment.

Flood problems related to agriculture, ecology, damage or those particular to the lower reaches of the Incomati, Maputo and other rivers in Mocambique were not included in this report.

2. THE STORM

2.1 Synoptic conditions

The following information was obtained from reference [1] and from K.E. Estié of the Pretoria Weather Bureau.

Cyclone Domoina was the fourth of the 10 tropical cyclones which had developed in the South West Indian Ocean in the 1983/84 summer season. She was spotted for the first time in the satellite photograph on 17 January as a mass of clouds north of Mauritius. It is seen in Figure 2.1 that the cyclone followed a south-westerly course until she reached Madagascar on 22 January. After causing heavy rain over the island, Domoina then followed a zig-zag route. On 27 January she reached the Mocambican coast (Photo 1). On 28 January it began to rain heavily in Maputo and within a radius of approximately 100 km. During the following three days Domoina moved slowly along the course shown in Figure 2.1 and was accompanied by sustained heavy rains. On 1 February, crossing the Zululand coast, she moved out to sea and quickly dissipated. The history of Domoina during those six days is illustrated by the daily synoptic weather maps shown in Figures 2.2a - 2.2f.

Tropical cyclone Imboa developed in the northern Mocambique Channel on 10 February and gradually moved southwards. On 18 February she reached the Zululand coast, but immediately turned back towards the sea (Figure 2.1). Heavy rains occurred only in a narrow belt. (Figure 3.5d).

2.2 Rainfall

2.2.1 Data

During the storm, daily rainfall figures were obtained from principal Weather Bureau Stations and a few Departmental dams. The number of these gauges was approximately 30. This information nevertheless permitted the drawing of daily provisional isohyetal maps which were essential for the collection of the bulk of rainfall data and for the immediate organisation and commencement of field surveys.

Appendix 1 contains daily and/or total rainfalls observed at more than 450 points (Figure 2.3). The principal sources of information were the following:

- Weather Bureau stations: These included more than 200 gauges in South Africa and Swaziland. Continuous autographic records were obtained from eight stations. Unfortunately, at Piet Retief and Makatini, where heavy rainfall was sustained during several days, the autographic recorder did not function or malfunctioned.

- Flood questionnaire returns: The Directorate of Hydrology posted hundreds of questionnaire forms to Post Offices located in the flood stricken districts of Eastern Transvaal and Northern Natal. The Postmasters were requested to place the forms in post boxes of farmers and others who were likely to have a raingauge. At the same time the Division of Agricultural Information was asked to read a communique in their radio program "Calling All Farmers" (= Landbou Radio) informing the farmers of the importance of completing and returning the questionnaire to the Department of Water Affairs. The result was very satisfactory because more than 200 forms were returned with valuable information on rainfall and floods. Without these rainfall data it would have been quite impossible to draw reliable isohyets in the areas of highest rainfall.

- Departmental dams: Daily rainfalls at 22 sites.

In addition to the above, rainfall data were also obtained from the Water Resources Branch of the Swaziland Ministry of Works, Power and Communications, the Direcção Nacional de Águas of Moçambique and from the Department of Agricultural Engineering of the University of Natal. The latter source provided a particularly valuable autographic record at the Umfolozi Game Reserve where more than 500 mm rain fell.

The average density of observations was close to 1 in 250 km^2, but was considerably sparser over the area east of longitude 32°E.

2.2.2 Rainfall distribution in space and time

Spatial distribution

The isohyetal map of the 5-day rainfall recorded between 28 January 08h00 and 2 February 08h00 is shown in Figure 2.4. The map reveals that the Eastern Escarpment was an efficient barrier in blocking the westward advance of heavy rain. Storm cells of 600 mm or more covered relatively extensive areas. The largest of these had maximum diagonal lengths of about 100 km. It stretched from Manzini (Swaziland) in the north to beyond Louwsburg in the south and generated the devastating floods in the Great Usutu, Ngwavuma, Pongolo and Mkuze Rivers. The maximum point rainfalls within this cell were: 740 mm in the Nhangano district, 850 mm north-east of Paulpietersburg and 730 mm just east of Louwsburg. Other cells with more than 600 mm total rainfall were situated in the Pigg's Peak area in Swaziland where the maximum point rainfall was 906 mm; in small areas in the Lebombo Mountains where at Ingwavuma 771 mm was recorded; in the Vryheid-Nongoma-Babanango triangle where in the upper Black Mfolozi catchment 924 mm rain fell and finally, in the coastal zone between Richards Bay and Sodwana Bay where up to 950 mm was recorded. Except in the coastal belt, the maximum rainfall cells were associated with mountainous relief. The highest recorded 1-day rainfall was 615 mm at Pigg's Peak. In the coastal belt of Southern Moçambique and Northern Natal similar or higher storm rainfall had already been recorded in the past. In the inland regions of South Western Swaziland, South Eastern Transvaal and Northern Natal, which lie 150 to 250 km from the shore, such high rainfall as the Domoina had not yet been observed, nor remembered by farmers living in the area.

TABLE 2.1: DEPTH VERSUS AREA VALUES OF TWO STORMS

Rainfall depth exceeded (mm)	Area (km^2)	
	July 1963	Domoina
100	58 000	107 000
200	25 000	93 800
300	7 500	68 800
400	1 000	47 000
500	250	18 500
600	50	9 000
641	0	5 500
700	-	1 750
800	-	125
950	-	0

In Northern Natal in the Mfolozi, Mkuze and Pongolo catchments the most severe flood on record had occurred in July 1963 and was generated by general rain. In Figure 2.5 the isohyetal map of the 2 - 5 July 1963 storm is shown. The recorded maximum 4-day rainfall was 641 mm near Hluhluwe. Compared with Domoina, the rainfall depth and area covered by this storm was much smaller and the position of maximum rainfall cells was much closer to the coast. To underline the magnitude and extent of cyclone Domoina in Table 2.1 depth versus area figures of the two storms are compared.

In Figure 2.6 the areal reduction curves of the two storms are compared with the curve obtained from Figures D20 and D25 of reference [2] for the 4-day probable maximum precipitation (PMP).

The isohyetal map in Figure 2.4 was used to calculate the 5-day areal storm rainfall for 83 catchments (Chapter 2.2.4).

Temporal distribution

Figure 2.7 shows the approximate daily position of the heaviest rainfall zone. The movement of this zone was very similar to the anti-clockwise movement of the cyclone centre (Figure 2.1).

In Table 2.2 daily rainfall figures of stations situated close to the course of storm centre are listed. The stations are arranged from Maputo to Cape St. Lucia along an anti-clockwise route.

TABLE 2.2: DAILY RAINFALLS AT SELECTED STATIONS

Station	Daily rainfall at 08h00 (mm)					5-day total rainfall (mm)
	29 Jan	30 Jan	31 Jan	1 Feb	2 Feb	
Maputo	96	99	9	35	-	239
Komatipoort	85	84	52	37	-	258
Pigg's Peak	225	615	60	6	-	906
Mbabane	45	393	52	17	3	510
Piet Retief	3	186	185	140	10	524
Louwsburg	-	181	245	113	-	539
Nongoma	10	75	164	125	28	402
Hluhluwe Dam	14	23	87	197	26	347
Cape St. Lucia	-	11	20	548	123	702

The shift of the day of maximum rainfall is evident. Appendix 1 and Table 2.2 reveal that at most places the sustained heavy rain lasted about two to three days. However, along the eastern side of the Lebombo Mountains, especially in the Pongolapoort - Goba reach, the sustained rain lasted four to five days as shown in Table 2.3.

TABLE 2.3: DAILY RAINFALLS ALONG THE EASTERN SIDE OF THE LEBOMBO MOUNTAINS

Station	Daily rainfall at 08h00 (mm)					5-day total rainfall (mm)
	29 Jan	30 Jan	31 Jan	1 Feb	2 Feb	
Goba*	97	201	72	60	-	430
Ingwavuma	130	275	122	206	38	771
Pongolapoort Dam	69	109	163	82	50	473

* in Mocambique

The continuous time distribution of rainfall was monitored by a number of autographic gauges. Figure 2.8 shows the accumulated rainfall versus time diagrams at five stations. At Matsapa Airport (Swaziland), the Umfolozi Game Reserve and at Richards Bay heavy rain fell. Though the total amount of rainfall and the maximum rainfall intensity were different, the general shape of the three curves is remarkably similar. The time-lag corresponding to the gradual movement of the heaviest rainfall from Matsapa to Richards Bay is neatly displayed by the diagrams. The diagram at Nelspruit and Newcastle serves as background information. Both places were situated at the edge of the heavy rain zone, but were characterized by differing rainfall intensities. At Nelspruit most of the rain fell on only one day. At Newcastle the rainfall intensity was fairly even for approximately $2^1/2$ days.

Figure 2.9a is the pluviograph recorded in the Umfolozi Game Reserve between 30 January 00h00-1 February 12h00. The two spells of very heavy rain sustained during several hours in the morning of 31 January were undoubtedly responsible for the extreme flood peak in the Mfolozi River which destroyed the N2 road bridge and the railway bridge near Mtubatuba. In Figure 2.9b the maximum rainfall intensity versus duration values, as obtained from the pluviograph, is plotted. The points seem to follow a well defined line which was characteristic for Domoina. The line may be used for the estimation of critical rainfall intensity, for durations between 1 hour and 72 hours, at any site where heavy rain, say $P>300$ mm, was experienced during the cyclone.

2.2.3 Frequency

Figure 2.10 shows the isohyetal map of the 3-day 200 year point rainfall in the region. It was based on Adamson's analysis of Southern African storm rainfall [3]. The shaded surfaces indicate areas where the Domoina rainfall was equal or greater than the 3-day 200 year point rainfall (Note: at most stations 90 to 100% of the Domoina rain fell in three days). The huge area of the total shaded surface, approximately 32 000 km^2, is evidence of the singular magnitude of the event. For the sake of interest it is recalled that during the 23 - 25 January 1981 South Western Cape storm, which caused the Laingsburg disaster and unprecedented floods elsewhere in the region, the 3-day 200 year point rainfall had been exceeded over an area of only 4 000 km^2.

In Table 2.4 the highest recorded intensities in the Umfolozi Game Reserve (Figure 2.9) are compared with the calculated 100 year intensities at Makatini Flats for durations of 5 minutes to 24 hours. This information was kindly made available by Professor R. Schulze of the University of Natal.

TABLE 2.4: COMPARISON OF RAINFALL INTENSITIES

Site and Event	Intensity (mm/h)								
	5 min	15 min	30 min	1 h	2 h	4 h	6 h	12 h	24 h
Umfolozi Game Reserve Domoina	95,6	83,4	74,8	64,0	52,9	38,8	36,2	23,5	15,8
Makatini Flats 100 year event	268	168	114	76,4	46,5	27,8	21,4	12,1	7,8

It is seen that the relative severity of the Domoina rainfall intensity increased with the duration and it exceeded the 100 year Makatini Flats value already at the relatively short duration of 2 hours.

2.2.4 Rainfall in 83 catchments

The calculation of the total Domoina rainfall over the catchment areas of surveyed or recorded flood peak sites served multiple purposes. Firstly, it was necessary for the calculation of storm run-off percentages at sites where flood hydrographs were recorded. Secondly, it was required for a qualitative evaluation of flood peak accuracy. Thirdly, a comparison of the Domoina rainfall with the PMP areal rainfall in catchments hit by maximum storm cells was regarded as helpful in ascertaining whether the surveyed flood peak was reasonably close to a practical upper limit.

The Domoina rainfall over 83 catchments was computed from the 1:500 000 master isohyetal map of Figure 2.4 by planimetry. The results are listed in Column 19 of Appendix 2. The accuracy is strongly linked to the density of rainfall observations and the variability of the rainfall pattern. As the average density of observations was close to 1 in 250 km^2 it is expected that in catchments much smaller than 250 km^2, say 100 km^2 or smaller, the accuracy is unknown. In larger catchments the accuracy should be reasonably good, because the general rainfall pattern emerges clearly from the isohyetal map. In the coastal areas east of the Lebombo Mountains the reliability of isohyets and catchment rainfalls is somewhat worse because of sparse data. For Sites 84 and 85 in the Incomati River in Moçambique the catchment rainfall was not calculated due to insufficient information.

In Column 18 of Appendix 2 the maximum observed point rainfalls are shown and in Column 20 the 3-day 200 year areal rainfalls are listed. The latter were obtained from Figure 2.10 by applying geographically centred areal reduction coefficients [4].

An inspection of Column 19 and 20 shows that for more than 55 catchments out of 83 the Domoina rainfall was higher than the 3-day 200 year value. From Figures 2.4 and 2.10 it is seen that, relatively, the heaviest rainfall occurred in the catchments of the Umbeluzi, Great Usutu, Ngwavuma, Pongolo and Mfolozi Rivers. In these catchments the Domoina rainfall was in the order of the expected 3-day PMP precipitation, see Table 2.5. The areal PMP rainfalls were calculated from reference [2].

TABLE 2.5: DOMOINA RAINFALL VERSUS PMP IN SELECTED CATCHMENTS

Site No.	River	Catchment area (km^2)	Areal rainfall (mm)	
			Domoina	3-day PMP
12	White Mfolozi	3 939	460	590
16	Black Mfolozi	1 635	610	655
19	Mfolozi	9 248	500	530
28	Pongolo	5 788	630	560
32	Pongolo	7 831	570	540
33	Ngwavuma	1 660	590	655
48	Great Usutu	17 974	460	440
49	Maputo	31 600	500	340
51	Umbeluzi	3 250	495	610

3. TROPICAL CYCLONES IN THE SOUTH WEST INDIAN OCEAN

The subject is described in detail in references [5] and [6].

3.1 Characteristics of tropical cyclones

Tropical cyclones are circularly symmetrical low pressure systems comprising cumulonimbus cloud enclosing a clear central area called the 'eye' (Figure 3.1a). The 'eye' is calm, dry and hot relative to the surrounding atmosphere and pressure is very low. Moving away from the 'eye' one first encounters a 'wall' of cloud with a steep temperature gradient and high wind speed followed by a gradual decrease in temperature and wind speed but an increase in pressure. Figure 3.1b shows a tropical cyclone as represented on a daily synoptic chart issued by the Pretoria Weather Bureau.

Tropical cyclones are formed from pre-existing disturbances which have an anti-cyclonic upper circulation. This results in high level divergence and low level convergence. The latter causes an inflow of moist, warm air to the disturbance. Tropical cyclones are generated between latitudes 5° and 30° north and south from the equator where the sea-surface temperature is high.

3.2 Data sources

Information sources from South Africa, Madagascar, Mauritius and Reunion are listed in Table 3.1

TABLE 3.1: DATA SOURCES

Source	Record	
	Start	Length (year)
Royal Alfred Observatory Publications: Mauritius	1814	122*
SA Naval Forecasting Office Charts: Simonstown	1940	7
SA Weather Bureau Charts	1940	44
SA Weather Bureau Newsletter	1954	30
Madagascar Meteorological Service Charts	1960	10
Reunion Meteorological Service Reports	1965	19

* incomplete

Other valuable data were found in reports published by the French and Mocambican Meteorological Service [5], [7]. These comprise a list of cyclones observed in the South West Indian Ocean before 1961 and include information on their path and associated weather.

3.3 Frequency in time and space

From the above sources it has been possible to compile a fairly complete list of tropical cyclones occurring in the South West Indian Ocean since 1927. This is summarized in Figure 3.2 which shows the annual frequency of tropical cyclones in the area. Events occurring west of Madagascar are shown separately as well. It is seen that, annually, about 10 cyclones are generated in the South West Indian Ocean and that four enter or originate in the Mocambique Channel.

Table 3.2 shows the monthly frequency of tropical cyclones observed in the South West Indian Ocean since 1848.

TABLE 3.2: MONTHLY FREQUENCY OF TROPICAL CYCLONES SINCE 1848

Month	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total number
% of total	1	2	3	13	30	26	17	6	2	934

Figure 3.3 shows the spatial distribution of tropical cyclone tracks west of Madagascar. It is seen that relatively few penetrate the African Continent or cross-latitude 30°S.

3.4 Tropical cyclones affecting South Africa since 1950

Figure 3.4 shows the path of cyclones causing significant rainfall (in excess of 100 mm) over the Transvaal or Natal since 1950. Of the 10 cyclones only Domoina has traversed South Africa.

Isohyetal maps were drawn for each cyclone. Four of these maps are shown in Figure 3.5. It appears that the Eastern Escarpment was an efficient barrier against the penetration of cyclones to the Highveld. Unfortunately, daily rainfall for the required periods was not available from Zimbabwe or Mocambique, thus rainfall depths and volumes refer to South Africa only. Table 3.3 lists relevant information for the events.

TABLE 3.3: SUMMARY OF RELEVANT DATA ON 10 CYCLONES

Date	Tropical cyclone	Storm rainfall (P>100 mm)		
		Area (km^2)	Depth (mm)	Volume (10^6 m^3)
Feb. 1956	'A'	65 000	155	10 000
Dec. '57/Jan. '58	Astrid	82 000	230	19 000
Jan/Feb. 1960	Brigette	49 000	155	7 600
Dec. '65/Jan. '66	Claude	24 000	175	4 200
Feb. 1972	Caroline	10 200	170	1 700
Feb. 1972	Eugenie	101 000	150	15 000
Jan. 1976	Danae	66 000	175	12 000
Feb. 1977	Emilie	53 000	180	9 500
Jan. 1984	Domoina	107 000	370	40 000
Feb. 1984	Imboa	26 000	155	4 000

3.5 The Domoina rainfall in perspective

As mentioned in Chapter 2, cyclone Domoina caused the highest observed rainfalls to date (1985), over considerable areas of Northern Natal, South Eastern Transvaal and Swaziland. A comparison of the Domoina rainfall with those experienced over Reunion and Madagascar [5] revealed the following:

- Reunion: maximum 24 hour rainfalls of 1 000 mm or more were recorded on several occasions. The world record for 24 hours, 1 870 mm, had been observed in Reunion. These exceptional precipitations are caused by the high mountainous relief.

- Madagascar: the highest recorded 3- to 5-day rainfalls were 600 to 800 mm, and are thus comparable to the Domoina rainfall.

- The great difference between the islands of the South-West Indian Ocean and the African Continent is that the former experience several cyclones annually and it is not rare that a violent cyclone is followed by a second one within days. The result is that the rain from the second cyclone falls on saturated catchments and generates very high run-off with extremely high flood peaks. Over the Continent, and especially over South Africa, the chance that two consecutive cyclones will penetrate inland and cause heavy rain is much smaller.

Out of the total number of cyclones observed in the South West Indian Ocean since 1950, 33% entered the Moçambique Channel, only 4% caused heavy rainfall in South Africa and the only cyclone-centre to penetrate the country was that of Domoina.

Nothing certain can be said about the risk of repetition of a Domoina size event. However, the observed cyclone tracks (since 1927) suggest that there exists a real possibility that a similar event (in terms of penetration and residence) could take place within a few decades. The greatest chance for this to happen is in the Eastern Transvaal Lowveld and Northern Transvaal.

4. FIELD SURVEY

The 85 flood peak measurement sites are shown in Figure 4.1. The selection of the sites was based on a preliminary storm isohyetal map and a ground inspection of the flood affected areas.

The field survey comprised slope-area reaches, bridge sites, flow gauging stations and dams. It started a few days after the flood, as soon as it was possible to reach the sites, and lasted on average for three weeks. The survey work was divided among four teams who were operating within previously delimited regions. Each team consisted of five to seven persons under the leadership of an experienced engineer or hydrologist and included persons who knew the region well. These teams and the data collectors of the Hydro-Regional Offices gathered information at 75 sites. At 10 sites the flood data were obtained from other sources (Column 22 of Appendix 2).

The main difficulties encountered during the survey were as follows:

- on steep rocky banks or in thick bush it was hard to find good flood marks (Photo's 12, 50)
- the use of light boats in strong currents was hazardous
- heat shimmer during midday
- frequent rains caused delays. In the southern coastal sector (Sites 6 to 9) the heavy rains of tropical cyclone Imboa made the identification of Domoina flood marks difficult
- presence of crocodile and hippopotami was a danger
- a shortage of tacheometers

4.1 Slope-area surveys (SA)

Number of sites: 42. This includes surveys in Swaziland and Moçambique and also those stations where the flood volume and time of peak were obtained from flow gauging records.

At SA stations the field work comprised the survey of a longitudinal flood profile defined by flood marks, one to five cross-sections and the estimation of absolute roughness at each cross-section. Photographs were also taken and a sketch of the reach was drawn.

SA surveys were carried out mainly at those sites where high flood peaks were suspected. Many of the surveys were conducted near to flow gauging weirs with the purpose of obtaining a pair of stage-discharge values for the extrapolation of the weir calibration curve. At three sites independent SA and bridge contraction surveys were done. Sites 37, 47, 48 and 58 were surveyed in Swaziland.

The selection of river reaches and the survey were done in accordance with standard rules derived from hydraulic considerations and years of practice [8]. Past experience has shown that the success of SA measurements depends to a large degree on a reliable longitudinal flood profile. The best way to obtain it is to survey as many flood marks as possible between the cross-sections and both upstream and downstream of the reach. The most common and reliable flood marks were debris on ground and tree trunks. The surveyed cross-sections represent post flood areas. It should be mentioned that two circumstances tend to cause an increase in surveyed cross-sectional areas: (i) any deviation from a perpendicular section to the flow direction will result in larger area and (ii) high velocity and rough water surface near riverbanks will result in the representative flood lines being higher than the true ones.

Problems related to alluvial river reaches are dealt with in Chapters 5 and 7. The estimation of absolute roughness was based on criteria set out in references [8] and [9].

Figure 4.2 shows the plan, flood profile and cross-section in a very favourable reach in the Komati River (Site 56) characterised by a clean, straight and uniform main channel, a narrow band of trees on the banks and uniform slope (Photo 48). An equally good SA reach is shown in Photo 44 (Site 33). In Figure 4.3 similar information is shown at Site 22 in the Mkuze River. This reach included a sharp bend and the slope was non-uniform. Note in the flood profile the super elevation of the right bank flood marks in the bend between Sections 2 and 3.

Various SA reaches are shown in Photo's 2, 10, 11, 13, 16, 34 and 51.

At 16 SA sites, mainly in alluvial river channels, bed soil samples were taken and a grading analysis was performed. Results are shown in Figure 7.2 (a - x).

4.2 Bridge contractions (B)

Number of sites: 7

The field work included a survey of flood marks upstream and downstream of the bridge in order to define the drop in water level, the contracted cross-section, an approach section and a typical river section downstream of the structure. Also absolute roughness estimates were made, photographs were taken and sketches were drawn. The surveys were done in accordance with the currently valid criteria [8].

Bridge surveys were carried out at sites where high flood peaks were suspected. The relatively small number of sites is due to the fact that many prospective bridge sites had to be abandoned because

- bridge and/or approach embankments were washed away (Photo's 7, 8, 11, 39)
- bridge deck was overtopped to such an extent that it ceased to act as a control
- the drop in water level across the contraction was too small
- excessive erosion in contracted section
- bridge openings were blocked by debris (Photo 31)

TABLE 4.1: STATISTICS OF SURVEYED DATA AT SLOPE-AREA SITES

Site No.	No. of cross-sections	Length of reach (m)	Mean top width (m)	No. of flood marks	No. of surveyed points/ section	Soil samples
3	4	472	154	20	21	
4	1	-	67	11	11	
8	4	432	129	35	26	+
11	3	335	145	55	17	
12	4	890	294	50	16	+
13	4	1 270	281	37	20	+
14	4	415	112	23	12	
15	3	243	52	15	9	
16	5	1 040	190	26	14	+
17	4	682	771	18	28	+
18	4	1 320	505	28	24	+
20	1	-	150	7	22	
22	4	1 040	143	43	16	+
23	4	708	252	24	23	
25	1	-	75	7	12	
26	4	633	92	33	12	
27	4	640	174	40	15	
29	3	747	313	44	32	+
30	5	1 010	282	44	24	+
31	3	587	381	36	24	+
33	4	503	185	40	25	+
34	4	625	72	30	15	
35	4	405	67	41	9	
36	4	681	95	50	16	
37	3	621	167	25	14	
38	5	120	64	25	16	
46	5	207	100	14	24	
47	1	-	329	14	16	
48	3	2 540	625	32	18	+
54B	4	410	88	40	16	
56	4	915	164	43	15	+
58	4	569	116	40	14	
59	3	299	160	19	14	
60	4	498	127	52	13	
61	4	572	229	44	22	+
73	3	280	160	12	15	
76	4	295	35	28	10	
77	3	224	110	17	20	
78	3	414	194	19	17	
81	4	1 080	253	51	15	+
82	3	1 080	410	59	22	

Figure 4.4 shows the plan, flood profile and cross-sections at the old Kruger-bridge on the Bivane River (Site 26). This site was hydraulically satisfactory because of right-angle crossing, large

drop in water level, no overtopping of deck and relatively stable channel-bed.

4.3 River flow gauging stations (G)

Number of sites: 30 (including Swaziland and Mocambique)

The field work was limited to the removal of the recorder chart and, in some cases, the establishment of the flood profile in the vicinity of the weir by a survey of flood marks.

The Domoina floods caused great havoc to the Departmental flow measuring network: 19 recording towers and gauge plates were washed away and many more stations were damaged to a lesser or greater degree. In the Mfolozi, Mkuze and Pongolo River catchments all stations east of longitude 30°E were seriously damaged and no records were available (Photo's 7, 21). The total damage to gauging stations was approximately R600 000. Photo 2 shows gauging station W1M09 in the Mhlatuze river (Site 8) which has survived both the Domoina and Imboa floods.

The flood peak at many of the gauging stations was relatively modest. These stations were nevertheless included in the documentation because the flood hydrograph and the time of peak are valuable data.

4.4 Dam (D)

Number of sites: 10 (including Swaziland)

Except for the removal of recorder charts the field work was restricted to the survey of eight cross-sections in the Pongolapoort Dam. By comparing reservoir bed levels surveyed in 1955, before the dam was built, with those of the recent survey the volume of the sediment deposit in the dam could be roughly estimated (Chapter 7.3). The survey was carried out with a light motor boat. Depth soundings were taken at 10 to 15 points in each section by using a 100 m tape attached to a weight. Great care was taken to ensure it remained vertical during the measurement. To determine the position of the boat a method sketched in Figure 4.5 was used. The co-ordinates of the intersection of two rays were determined from their bearings from two stations of known co-ordinates. Two tacheometers were set up on these stations and their positions were checked by observing the angles between three reference objects (RO1, RO2 and RO3) of known co-ordinates. The bearings øAC and øBC were observed from the tacheometric stations. The co-ordinates of the intersection were calculated by the formula shown in Figure 4.5.

Errors in sounding depths were due to the pitching of the boat and were less than 1,5 m. Errors in the horizontal plane can be attributed to difficulties in transferring the positions (fixed on

1:50 000 scale map) of the recent survey to the 1:6000 scale map of 1955. Maximum errors were between 15 and 50 m.

The detailed mapping of the reservoir bed by echo-sounding was delayed by the repairs to the surveying launch and results were not available at the time of completing this report.

4.5 Other sources of information

Moçambique [23] [24]

The Direcção Nacional de Águas provided a number of hydrographs at their river flow gauging stations in the Umbeluzi and Incomati Rivers. Five of these, Sites 52 and 53 in the Umbeluzi and Sites 83, 84 and 85 in the Incomati, were of great value for this documentation. The flood hydrographs were obtained from extrapolated stage-discharge curves. At Madubula in the Maputo River (Site 49) the flood peak was obtained from a slope-area calculation.

Swaziland

The Water Resources Branch of the Ministry of Works, Power and Communications provided assistance for the survey at four slope-area stations in the Great Usutu, Mkondvo and Mlumati Rivers and furnished flood flow information at Sites 50 and 51 in the Black Imbuluzi River. A complete flood hydrograph recorded at the Iysis weir in the Komati River (Site 55) was obtained from the Commonwealth Development Corporation via Chunnett, Fourie and Partners (Consulting Engineers).

Various

The following information obtained from diverse sources has greatly contributed to the improvement of this documentation both in a quantitative and qualitative sense:

- Flood peak at Site 62 in the Ngweti River from Heliboma Fibris Pty Ltd.
- Time of maximum flood level, wave heights in rivers, flood damage, erosion and data on historic floods from the flood questionnaire returns supplied by inhabitants.
- Photographs: the source or author, if other than the Directorate of Hydrology, are indicated in each case after the title.
- LANDSAT images taken before and after Domoina.
- Aerial photographs taken along the Mfolozi, Mkuze and Pongola Rivers.

- Bridge plans.
- Flood line survey by the National Roads, Department of Transport in the vicinity of the N2 road bridge over the Mfolozi River
- Video films, in particular the excellent film made by the Natal Roads Department.
- Cross-sections surveyed in the Mfolozi River at the N2 road bridge by the Natal Roads Department and at the downstream railway bridge by the South African Railways.

5. FLOOD PEAKS

The main purpose of the flood survey was to gather sufficient data for the calculation of high to extreme peak discharges. The importance of these is twofold:

(i) Associated with a return period or Francou-Rodier coefficient 'K' essential information can be provided for design flood calculations.

(ii) Associated with the maximum flood level recorded at river flow gauging stations an important, if approximate, point can be provided for the extrapolation of stage-discharge curves. The more exceptional the flood peak, the more worthy is the calibration point.

5.1 Methods of calculation

5.1.1 Slope-area method

In this method the peak discharge was calculated by a (i) uniform or (ii) quasi-uniform flow equation from the flood profile, cross- sections and roughness.

(i) Uniform flow: the Chézy equation was applied at each cross-section with the local flood profile slope.

(ii) Quasi-uniform flow: the slope-area equation was applied for each sub-reach between two cross-sections. The slope-area equation is based on the Chézy equation, but the change in velocity-head is taken into account i.e., the flow is treated as gradually varied.

These methods were applied according to well established Departmental standards [8], [9]. Therefore only the following two aspects are mentioned:

1. Representative cross-section

Surveyed post flood cross-sections were assumed to be the same as the unknown 'true' areas during flood peak conditions. This is a realistic approximation in non-alluvial channels where erosion or deposition are not significant. In alluvial channels, where the riverbed and banks consist of unconsolidated sediments, it is impossible to furnish direct proof of the above assumption without continuous monitoring of the cross-section perimeter during the flood. However, in Chapter 7.2 (Figure 7.3) a comparison of equilibrium cross-section areas with the surveyed ones suggests that, on the average, the assumption is acceptable. This conclusion is supported by the comparison of surveyed pre- and post Domoina cross-sections in the Mfolozi Rivers (Chapter 7.4, Figures 7.5 and 7.6).

2. Roughness

The absolute roughness and the Chézy resistance coefficient were determined as described in references [8], [9]. The essentials are recapitulated as follows:

(i) Absolute roughness ε (m) is:

- 1 to 2 times the diameter of dominant obstacles
- ε_{min} is the smaller of 0,15R or 0,2 m in uniform river reaches (R = hydraulic radius)
- ε_{max} is the mean water depth in those parts of the cross-section where trees or bush are higher than the water depth during peak flow

(ii) Chézy coefficient $C = 18 \log \frac{6R}{\varepsilon}$ $(m^{0,5}/s)$

Under normal circumstances, particularly in non-alluvial rivers, ε can be estimated with relative ease. In a typical case even an error by a factor of 2 in the estimation of ε will result in an error of only ~ 20% in the calculated discharge.

During this survey some doubt arose as to the choice of representative ε values which prevailed during peak flow conditions in rivers where extreme floods occurred. The doubts were especially strong in the case of alluvial channels characterized by continuous and significant changes of roughness during floods. Here, depending on the Froude number ($F_r = v/\sqrt{gh}$ where v = velocity, g = acceleration of gravity and h = water depth) an originally smooth sandy channel bed can be transformed into ripples, dunes, flat-bed and antidunes. Up to $F_r \simeq 0,3$ the dominant bed form are dunes associated with high resistance. Antidunes appear if $F_r > 0,6$ and are characterised by average resistance. In the wide range of $0,3 < F_r < 0,6$, which had been the case at many slope-area sites (Table 5.1), all bedforms may coexist. If the riverbed is washed out flat the resistance will be very small even as low as one third of dune resistance [10], [11]. Heavy suspended sediment load tends to dampen turbulence i.e., the result will be decreased resistance. On the other hand, extreme floods are characterised by heavy bed-load transport as well, which includes large stones, boulders, debris of all kind etc. The movement of bed-load is brief and jerky and its velocity is less than 15% of the mean flow velocity [11]. In other words, the huge pieces or heaps of bed-load act as substantial resistance to the flow and can cause standing waves. Another source of increased resistance are the masses of soil, rocks and vegetation violently entering the flow after collapse of steep banks and landslides from adjacent hill slopes. Finally, the washout of erodible river channel material means that the resistance will be essentially determined by the roughness of the base rocks which can be very large. During Domoina all the abovementioned factors did exist.

In estimating the absolute roughness in the main channel of rivers where extreme floods occurred, the existence of huge surface waves during peak flow proved to be the most reliable help. Photographs (3, 38), video-films and eye witnesses have confirmed that during high flood conditions in the Mfolozi, Mkuze and Pongolo Rivers waves of 1 to 3 m height were characteristic in the main channel in the regions of maximum velocities. (At or near fixed obstacles, such as bridges or weirs, the wave height reached in some cases 5 m (*Photo's 5, 6, 28*)). The basis for the estimation of absolute roughness is provided by the specific energy curve which defines the changes in water level that occur if bed elevation changes locally [11]. In practical terms this means that in subcritical flow, surface waves are an indication of bottom roughness of nearly the same height. In the case of supercritical flow the bottom roughness is 0,5 to 0,6 times the height of the surface wave.

Relevant hydraulic parameters at 41 SA stations are listed in Table 5.1.

Noteworthy conclusions from this table are the following:

- With a few exceptions the slope of the surveyed flood line and the slope obtained from the 1:50 000 scale contour maps show a fair agreement.

- The mean velocity in the main channel did not exceed 5 m/s. (Eye witnesses reported surface velocities of about 10 m/s).

- Unstable or supercritical flow ($F_r > 0,8$) occurred at only six sites where the channel slope was relatively steep. As a rule of thumb, the slope should be about 0,01 (= 1%) to produce supercritical flow in natural channels.

TABLE 5.1: HYDRAULIC PARAMETERS AT 41 SLOPE-AREA SITES

				Slope		Cross-section		Main channel (mean values)			
Site No.	No. of cross-sections	Catchment area	Peak discharge	Surveyed flood line	Bottom from 1:50 000 maps	Mean area	Mean top width	Maximum depth	Absolute roughness E	Velocity V	Froude number F_R
-	-	km²	m³/s	m/m	m/m	m²	m	m	m	m/s	
1	2	3	4	5	6	7	8	9	10	11	12
3	4	5 887	1 190	0,0016	0,0034	466	154	7,8	0,35	2,6	0,46
4	1	104	291	0,0050	0,0043	95	69	5,3	0,35	3,7	0,81
8	4	2 409	2 400	0,0030	0,0013	608	129	7,3	0,55	4,2	0,44
11	3	432	1 050	0,0110	0,0063	282	145	5,2	0,75	4,0	0,92
12	4	3 939	7 500	0,0025	0,0023	2 017	301	9,5	0,75	3,9	0,54
13	4	4 776	6 500	0,0010	0,0015	2 130	281	13,2	0,55	3,1	0,38
14	4	238	2 180	0,0062	0,0038	441	112	7,0	0,55	4,5	0,81
15	3	78	580	0,0107	0,0090	140	52	4,0	0,65	4,2	0,95
16	5	1 635	7 500	0,0023	0,0023	1 713	190	13,7	1,05	5,0	0,59
17	4	3 396	10 000	0,0012	0,0012	3 470	771	16,5	0,55	3,6	0,41
18	4	9 216	16 000	0,00056	0,00055	6 228	505	18,0	1,35	2,8	0,27
20	1	516	2 050	0,0033	0,0023	748	150	11,4	1,80	2,7	0,43
22	4	1 467	3 100	0,0056	0,0031	676	143	7,1	0,90	4,7	0,72
23	4	2 647	5 500	0,0016	0,0013	1 620	252	11,1	0,60	3,4	0,46
25	1	62	230	0,0167	0,0167	71	75	4,2	0,40	4,9	1,09
26	4	878	855	0,0035	0,0038	321	92	7,1	0,80	2,0	0,35
27	4	426	3 020	0,0050	0,0066	692	174	8,0	0,65	4,8	0,74
29	3	6 110	9 800	0,0026	0,0019	2 250	313	12,9	0,50	4,7	0,61
30	5	6 846	11 000	0,0020	0,0032	2 450	282	12,8	0,65	4,5	0,52
31	3	6 955	11 500	0,0016	0,0012	3 020	381	14,7	0,75	4,1	0,49
33	4	1 660	4 250	0,0024	0,0023	1 050	185	10,4	0,45	4,3	0,58
34	4	1 652	500	0,0014	0,00090	206	72	7,3	0,20	2,3	0,44
35	4	180	400	0,0044	0,0066	152	67	4,9	0,60	2,7	0,61
36	4	2 313	1 400	0,0030	0,0038	442	95	8,3	0,50	3,6	0,58
37	3	3 844	4 900	0,0029	0,0031	1 160	167	11,5	0,65	4,5	0,60
38	5	732	300	0,0053	0,0024	129	64	4,1	0,70	3,1	0,61
46	5	1 446	509	0,0036	0,0021	210	100	4,1	0,35	3,2	0,62
47	1	5 170	4 740	0,0013	0,0025	2 060	329	9,4	1,35	2,3	0,34
48	3	17 974	11 300	0,00057	0,0018	4 550	625	14,3	0,45	2,6	0,30
54B	4	5 509	832	0,0028	0,0032	288	95	5,4	0,35	3,1	0,57
56	4	8 040	2 640	0,00061	0,00062	1 100	164	11,6	0,50	2,3	0,30
58	4	642	1 800	0,0055	0,0059	455	116	6,4	0,55	4,4	0,77
59	3	940	2 100	0,0036	0,0019	621	160	9,0	0,55	4,1	0,63
60	4	1 119	2 150	0,0029	0,0019	620	127	9,5	0,75	3,5	0,54
61	4	10 785	3 100	0,00079	0,0019	1 290	229	9,3	0,40	2,6	0,34
73	3	320	700	0,0033	0,0022	348	148	4,6	0,80	2,4	0,49
76	4	73	175	0,0108	0,0140	53	33	3,0	0,45	3,5	0,92
77	3	1 639	1 370	0,0048	0,0048	409	110	7,1	0,85	3,4	0,64
78	3	8 479	1 100	0,0039	0,0024	451	194	5,0	1,45	2,6	0,49
81	4	10 365	1 800	0,0014	0,0012	991	251	7,1	0,60	2,5	0,40
82	3	21 480	4 750	0,0043	0,0019	1 790	395	8,6	1,75	3,1	0,55

5.1.2 Bridge contractions

The methods used included those of the United States Geological Survey, D'Aubuisson equation, broad-crested weir equation, orifice flow and pipe flow. Practical applications are described in references [8] and [9].

The calculation of peak discharge at the destroyed N2 road bridge on the Mfolozi River near Mtubatuba (Site 19) needs some comment. The bridge was washed away on the afternoon of 31 January, a few hours before the flood peak. Only the two piers nearest to the left bank remained (Photo's 18, 20). From earlier sub-soil investigations carried out at the bridge site by the Natal Roads Department and the National Institute for Road Research [12] it appeared that the thickness of the alluvial riverbed which consists mainly of fine sand is 30 m or deeper, except near the south bank where the solid rock rises steeply to the surface. The surveyed post Domoina channel-bed is shown in Figure 7.6 as a continuous line. In contrast to previous surveys which represent natural (dotted line) or slightly disturbed (dashed line) conditions, the post Domoina bed is characterised by fairly uniform depth across the entire constriction. (Pre- and post-Domoina cross-sections are discussed in Chapter 7.4.2).

The flood peak at the bridge contraction was calculated as follows:

(i) A provisional peak was calculated from the surveyed approach - and constricted sections (Q').

(ii) A theoretical scour depth was estimated in the constriction, assuming general sediment transport conditions. The formulae applied were

$$e = h_2 - h_1 + \frac{v_2^2 - v_1^2}{2g} \quad \text{and} \quad h_2 = h_1 \left(\frac{B_1}{B_2} \right)^{2/3}$$

where e = scour depth (caused by constriction)
h = mean flow depth
B = mean width
v = mean velocity

Suffix '1' refers to the approach (= unrestricted) section and suffix '2' refers to the constricted section. It was also assumed that no extra energy loss was caused by the geometry of the sudden constriction.

The resulting scour depth was $e \simeq 10$ m which is in fair agreement with the maximum scour estimated for the railway bridge constriction situated 1 500 m downstream [13], [14].

(iii) Peak discharge Q' was increased by $\Delta Q = 0{,}33\ v'e.B_2$ where v' is the mean velocity associated with Q' and e. B_2 is the extra scour below the surveyed constricted bed. The strong reduction of the mean velocity in the scoured section is justified by considering that in heavy bed-load transport the sediment moves at a very much lower velocity than the water (Chapter 5.1.1). Further, it can safely be assumed that at the time of maximum scour the representative upstream flood level was lower than the surveyed one [15].

It should be noted that local scour holes caused by piers and abutments are irrelevant for discharge calculations and were therefore not considered.

A representative flood line at the bridge was established by checking the surveyed flood mark levels with those of a very good independent survey carried out by the Natal Branch of the Department of Transport. The drop of water level across the bridge was Δh = 1,2 m.

In Table 5.2 various hydraulic parameters at the seven surveyed bridge sites are listed.

TABLE 5.2: HYDRAULIC INFORMATION AT BRIDGES

Site No.	Peak discharge Q(m^3/s)	Q/B* (m^2/s)	Hydraulic drop Δh (m)	Contraction ratio m**	Skewness *** ø(degree)	Flow type
5	1 200	20	0,70	0,45	90	free surface
15	587	16,8	2,10	0,31	90	free surface
19	15 400	65	1,20	0,38	85	free surface
24	2 750	42	1,55	0,49	55	pipe flow
26	1 060	29	1,75	0,35	90	free surface
35	600	10,3	1,95	0,37	77	free surface
74	230	12	0,10	-	90	culvert

Notes: * B = total width of contraction
** m = 0 means no contraction
*** ø = 90° means bridge crossing at right angles to flow

5.1.3 River gauging stations

At most river gauging stations the flood level exceeded the calibration limit: compare Columns 9 and 22 of Appendix 2. At such sites, whenever possible, an indirect flood peak survey (i.e., slope-area or bridge contraction) was carried out. At eight stations approximate flood peaks were determined either by a weir equation or an extrapolation of the log-log plot of the stage-discharge curve.

This is often an unsatisfactory approach and calls the attention to the urgent need for a more reliable extension of calibration at many gauging weirs in the region.

5.1.4 Dams

At dams the peak inflow was calculated from the recorded dam levels, the spillway and outlet discharges and the dam depth-capacity relationship by employing the basic continuity equation:

$$I = \theta + \frac{\Delta \Omega}{\Delta t} \qquad (m^3/s)$$

where I = inflow rate

θ = total outflow rate

$\frac{\Delta \Omega}{\Delta t}$ = rate of change in dam storage with respect of time

Only six of the 10 dams spilled. At the Pongolapoort Dam (Photo's 41 - 43) the outflow was controlled.

In the calculations horizontal dam levels were assumed which might not be true for extreme inflows, particularly in smaller dams. Furthermore, strong evidence has been gained during the last years in South Africa that the sudden inflow of extraordinary floods is accompanied by surges and, as a result, momentary higher water levels than the representative mean level will occur [9], [16], [17].

For the sake of interest in Table 5.3 the approximate values of surge wave height are given in four dams where large to extreme inflows occurred. The surge height was calculated from the wave velocity and continuity equations by assuming sudden rise of flow from zero to peak [17]:

$$h_s = D\left(\frac{C}{C - v} - 1\right)$$

where h_s = surge height (m)

D = mean water depth (m)

C = surge wave velocity = $\sqrt{gD}$ (m/s)

v = mean inflow velocity in dam = Q_i/a (m/s)

Q_i = inflow rate (m^3/s)

a = mean wet cross-section in dam (m^2)

TABLE 5.3: APPROXIMATE BASIC SURGE HEIGHTS IN FOUR DAMS

Site No.	Dam	Catchment area A (km^2)	Peak inflow* Q_i (m^3/s)	Surge height $h\Delta$ (m)
7	Goedertrouw	1 273	1 900	0,21
10	Klipfontein	340	1 090	0,20
21	Hluhluwe	734	2 940	0,70
32	Pongolapoort	7 831	16 800	0,50

* Calculated from basic continuity equation $I = \theta + \Delta\ \Omega/\Delta t$

It is seen that at Sites 21 and 32 the possibility of relatively high surges is great. It should be added that owing to transformation and reflection at the dam wall the peak surge could have been twice as high as indicated above.

The consequence of surges is that increasing super elevation of recorded dam levels during steeply rising hydrograph stages can lead to overestimation of the peak inflow rate by 20% or even more. During Domoina the catchment area of the Pongolapoort Dam received higher rainfall than the estimated PMP (Table 2.5) and it was suspected that the peak inflow of 16 800 m^3/s obtained from $\Delta\ \Omega/\Delta t$ storage increments was too high. To dispel uncertainty, a special effort was made to obtain flood peaks in the Pongolo River upstream of the dam by other methods. Sites 28 to 31 (Figure 4.1 and Appendix 2) were surveyed mainly for this purpose. The results confirmed the suspicion and provided further evidence to earlier experiences. The numerical comparison and further comments are included in Chapter 5.2.1 and Table 5.5.

5.2 *Evaluation of results*

The calculated peak discharges and pertaining parameters, such as maximum gauge height, return period, equivalent Francou-Rodier 'K', accuracy rating and time of peak are listed in Columns 9 - 14 of Appendix 2. In Column 15 the available previous maximum recorded peaks are shown. At a few stations in drainage region W1 flood peaks caused by tropical cyclone Imboa were also calculated and included in Appendix 2. The columns require the following clarifications:

Column 9: At gauging weirs the gauge height, GH, is the height of the maximum recorded flood level above the crest of the lowest notch. At SA Sites GH is the mean hydraulic depth $h_m = A/T$ (A = cross-section; T = top water width, both refer to main channel).

Column 11: At river flow gauging stations where the record of annual maximum flood peaks was at least 15 years long, the return period (T) was read off from the flood frequency distribution curve up to the T = 20 year limit. At all other sites the ratio of the flood peak (Q) to the regional maximum flood (RMF) as calculated by the Francou-Rodier equation [9], [16], [18]. Figure 5.3 was used to classify the flood peak in one of the following categories:

Q/RMF	Return period class (year)
< 0,2	< 20
0,2 - 0,5	20 - 50
0,5 - 0,65	50 - 200

At sites with Q/RMF > 0,65 the magnitude of flood was expressed only in terms of RMF. Important note: for the calculation of RMF the revised regional envelope 'K' values were used. (Chapter 5.2.3).

In a few cases and in the range of 10 < T <50 year the listed return period is the average value obtained from the two methods.

Column 13: In assigning accuracy ratings for each flood peak the main criterion was the quality of measurement. In addition, comparisons were made with peaks at neighbouring sites. The meaning of the rating symbols is the following:

Rating	Error in peak discharge
1	less than ± 10%
2	less than ± 30%
u	unknown

For details of criteria employed to decide upon an accuracy rating consult reference [9].

Column 14: The time of flood peak, whenever possible, was obtained from recorded flood hydrographs. At many sites the approximate time of maximum flood level was obtained from flood questionnaire returns. In absence of information only the month and day of the peak were indicated.

Column 15: The previous maximum flood peak was obtained from records at gauging stations, post-flood survey or from historical data of unknown origin.

5.2.1 Accuracy of flood peaks

In Table 5.4 the accuracy ratings are summarised according to method of measurement.

TABLE 5.4: SUMMARY OF PEAK DISCHARGE ACCURACY RATINGS

Method	No. of measurements	No. of ratings*			No. of peaks with T ≥ 50 years
		1	2	u	
Slope-area	42	12	25	5	20
Bridge	7	1	4	2	4
Gauging weir	30	17	12	1	3
Dam	10	6	4	-	3
Totals	89	38	43	8	30
%	100	43	48	9	34

* 1 = less than 10% error
2 = less than 30% error
u = unknown error

The above statistics are very similar to those of the January 1981 South Western Cape Floods [9] and confirms previous experience that the accuracy of the 'indirect' methods i.e., the slope-area and bridge-contraction, compare well with that of gauging weirs and dams. The two latter methods yielded proportionally more rating '1' peaks and fewer rating 'u' peaks. However, by far the greatest number of extreme peaks were calculated by the indirect methods. It can thus be concluded that under South African conditions the indirect methods are indispensable for the documentation of rare or exceptional floods. The number of sites where the accuracy could not be estimated (rating 'u') was small.

The quality and reliability of SA surveys is illustrated by the results in the Pongolo River (Table 5.5)

TABLE 5.5: COMPARISON OF FLOOD PEAKS ALONG THE PONGOLO RIVER

Site No.	Method	Catchment area A (km^2)	Peak Q(m^3/s)	Francou-Rodier 'K'	Rainfall* P (mm)	Time ** of concentration t_c(h)	Accuracy rating
24	B	1 731	2 750	4,62	480	18	2
28	G	5 788	9 200	5,19	630	31	1
29	SA	6 110	9 800	5,23	625	33	1
30	SA	6 846	11 000	5,30	590	40	1
31	SA	6 955	11 500	5,34	590	42	1
32	D	7 831	(16 800)	(5,68)	570	45 - 50	2
32	Corrected from 28 - 31:		13 000	5,41			

* See Column 19 of Appendix 2
** t_c = time taken by water to reach the site from the farthest point of the catchment

Comments: Based on criteria related exclusively to the quality of survey at any one of the individual sites, perhaps only Site 28 could have been qualified for rating '1'. (At this site a good flood line was surveyed upstream and downstream of an unsubmerged broad-crested weir). However, the SA surveys at Sites 29 - 31 yielded peak discharges which were consistent with Site 28. Consequently rating '1' could be justified for the four sites. Note that total storm rainfall P is increasing from Site 24 to Site 28 and decreases further downstream. The relative magnitude of the peak discharge ('K') is, on the contrary, gradually increasing from upstream to downstream. The reason is that the time of concentration of the respective catchments gradually approaches the effective storm duration (≃ 3 days).

The consistent (thus reliable) flood peaks obtained for Sites 28 - 31 were used to correct the exaggerated flood peak of 16 800 m^3/s in the Pongolapoort Dam which was calculated from 6-hour moving averages of hourly storage increments (Chapter 5.1.4 and 6). The corrected peak of 13 000 m^3/s was arrived at by linear extrapolation of upstream peaks according to catchment area. The overestimation by 3 800 m^3/s is very severe and equivalent to 29%.

Referring to Table 5.3 it seems very likely that the calculated peak inflow and outflow rates at Hluhluwe Dam (Site 21) are also noticeably higher than the true figure. Unfortunately no suitable site could be found in the neighbourhood for a control slope-area survey.

The fair quality of the indirect survey methods can easily be attested by comparing in Appendix 2 the calculated flood peaks upstream and downstream of confluences. Such sites are for instance 13, 17 and 18 in the Mfolozi catchment or Sites 61, 81, 82 and 83 near the confluence of the Komati and Crocodile Rivers.

5.2.2 Flood peak frequency distributions

At about one third of the sites the length of the annual maximum flood peak record was more than 15 years which is the minimum desirable period for statistical analyses. Amongst these there were only five stations where an extraordinary flood peak (T > 50 years) was observed. Figure 5.1 shows the observed and theoretical flood peak frequency distributions at Site 28 in the Pongolo River. The data were ranked according to the well known Weibull formula:

$$T = \frac{N + 1}{m} \quad (\text{or } p = \frac{100}{T})$$

where T = return period (year)
p = probability of exceedance (%)
N = length of record (years)
m = rank in descending order

The theoretical distributions were the Log-Normal 2 parameters (LN2) and the Log-Pearson III (LP 3).

Figure 5.1 underlines the insufficiency of statistical models to assign a reliable return period to extraordinary flood peaks. In this example the return period of the Domoina peak was indicated as only 80 years by the LP3 model, but more than 1 000 years by the LN2 model. It is worth noticing that the ratio of LP3 and LN2 peak flow forecasts becomes unacceptably high for return periods longer than 25 years.

The form of the observed frequency line is typical for catchments where heavy cyclonic rainfall does occur, such as in the eastern and south-eastern parts of the Subcontinent. It reveals that the flood regime is characterised by the presence of outliers i.e., peaks much larger than the next in rank. At Site 28 the Domoina peak was 2,5 times larger than the second ranked peak. It appears that the four biggest peaks are outliers. In other words, at about every 10 years heavy floods can be expected. The presence of outliers in an annual maximum flood peak record is an indication that the sample consists of a "mixed population" which cannot be adequately described by the currently employed probability distributions.

5.2.3 Revision of Francou-Rodier 'K' values and maximum flood peak region boundaries

The Francou-Rodier 'K' values are used to estimate the regional maximum flood (RMF) in South Africa [18]. In Figure 13 of reference [9] the boundaries of five regions are shown with the until now valid 'K' envelope values. In Column 12 of Appendix 2 the equivalent 'K' values of the Domoina peaks are listed. These values are also shown in Figure 5.2. At nine sites, all located in the Mfolozi or Pongolo catchments, these 'K' values are higher than the hitherto valid K = 5,25 envelope value. Consequently the need arose to correct both the envelope values and the regional boundaries. The revision is shown in Figure 5.3. The changes are the following:

(i) Region 1a (new): K = 5,60. This region comprises areas where the Domoina peaks were associated with K > 5,25 values or (learning from this experience and keeping in mind some of the conclusions from Chapter 3) where tropical cyclones could cause similarly high flood peaks in future. In deciding on the boundaries of region 1a much attention was paid to topography and distance from the Indian Ocean. Larger rivers which flow across this new region, but originate in the Transvaal Highveld where tropical cyclones are not expected to cause sustained heavy rains, will be associated with K = 5,25. Such rivers are the Great Usutu (with some of its main tributaries) and the Komati.

(ii) Region 1: K = 5,25. This region stretches now without interruption from the south coast to the Soutpansberg and also includes the western highlands of Swaziland.

(iii) Region 2: K = 5,00. The upper catchments of the Usutu and Komati Rivers, which originally belonged to region 3, have now been added to region 2.

(iv) Region 1b: K = 5,40. In anticipation of the first definitive general revision (due to be completed at the end of 1985) this additional new region was formed in the Port Elizabeth-Humansdorp area where heavy floods seem to occur at frequent intervals. In March 1981, for example, the peak inflow into Loerie Dam was slightly larger than RMF [16].

In Figure 5.4 all maximum flood peaks observed since 1951 in drainage region W, and associated with K > 4,0, were plotted against catchment area. (One peak was observed before 1951). This diagram demonstrates the overwhelming magnitude of the Domoina peaks and their tendency to follow the converging 'K' lines.

6. FLOOD HYDROGRAPHS

These were computed at 40 sites from water level records and were used for the calculation of flood volume and run-off percentage and for the determination of the time of peak. Figures 6.1 (a - p) show hydrographs at 16 sites where moderate to extraordinary floods occurred.

Unfortunately, in the Mfolozi, Mkuze, Hluhluwe and Pongolo Rivers, where the most extreme floods were experienced, all river gauging stations were seriously damaged or destroyed. Only in the Hluhluwe and Pongolapoort Dams were hydrographs recorded (Sites 21 and 32).

At dams both inflow and outflow hydrographs were computed. Considering the importance of Pongolapoort Dam, its hydrograph is shown in more detail in Figure 6.2 The dashed line represents the hydrograph computed from hourly dam level readings and the continuous line is the 6-hour moving average inflow. The oscillations of the 1-hour hydrograph appear too violent and cannot be explained by changing rainfall intensity in a catchment of nearly 8 000 km^2. The obvious causes of oscillations are seiching and surges. The seiching was due to atmospheric pressure differences that had to exist along the longitudinal axis of the main reservoir. The apparent seiching period is about 2 to 3 hours i.e., it had no appreciable influence on the 6-hour moving average hydrograph. There were no high surface wind speeds in the area. As for surges, it has already been concluded (Chapter 5.2.1) that these were responsible for a 29% overestimation of the peak inflow rate as obtained from the 6-hour moving average hydrograph. Perhaps the most remarkable feature of the 1-hour hydrograph in Figure 6.2 is that (i) the beginning of the huge fluctuations coincides with the sudden increase of flow around noon on 30 January and (ii) following the peak inflow the fluctuations become smaller, especially after the dam content had risen above 60%. This behaviour corresponds well to the changes of theoretical surge height calculated in the main reservoir and listed in Table 6.1. (The calculation of surge height was explained in Chapter 5.1.4).

TABLE 6.1: SURGE HEIGHT AND ASSOCIATED PARAMETERS AT VARIOUS DAM CONTENTS IN THE PONGOLAPOORT DAM

Dam content %	Inflow Q_i (m^3/s)	Mean depth D (m)	Mean velocity in dam V (m/s)	Surge height h_s (m)
20	6 000	10,2	0,23	0,23
35	16 800*	13,1	0,42	0,50
40	13 000	13,7	0,29	0,35
60	10 000	15,6	0,16	0,20
80	3 000	17,3	0,04	0,05

* Apparent 6-hour moving average value

6.1 Flood volume and run-off factors

The flood volume was computed as the total volume between the time of the apparent sudden rise of the hydrograph and a fixed time after the peak. This latter (t) was calculated from the following 'rule of thumb' formula [19]:

$$t = 0{,}8A^{0{,}2} \qquad \text{(days)}$$

where A = catchment area (km^2)

Care was taken to exclude those parts of the hydrograph generated by post-Domoina rains i.e., rainfall after 08h00, 2 February. The computed flood volumes appear in Columns 16 and 17 of Appendix 2 expressed in 10^6 m^3 (Ω) and mm (p) respectively.

The run-off percentages were calculated from Columns 17 and 19 as 100 p/P and appear in Column 21. In Figure 6.3 the run-off percentage was plotted against corresponding total storm rainfall (P). Only Site 3 was excluded because of unreliable record caused by sediment blockage.

The diagram is most instructive for it reflects the great influence of antecedent catchment wetness and vegetation on run-off percentage. The three lines shown correspond approximately to the following conditions:

Line 1: The 14-day antecedent rainfall (AP_{14}) was generally 50 to 100 mm. This is more or less equivalent to average January conditions in the area. The characteristic vegetation cover was grassveld. The run-off percentages along the line are slightly higher than given by Figure G.2 in reference [2].

Line II: AP_{14} was generally 20 to 50 mm. The vegetation was mainly bush and grassveld. This line seems to be fairly representative for most sites. Note that under the particular catchment wetness conditions approximately 50 mm storm rainfall was needed to start run-off.

Line III: AP_{14} was variable, but generally less than 50 mm. The predominant vegetation in catchments 66, 69, 70 and 71 which plot nearest to the line was forest plantations or orchards. The storm loss in these catchments was very high and apparently about 100 mm storm rainfall was needed to start run-off.

Figure 6.3 is useful to reveal inconsistent flow records, especially along the same river. For instance, Sites 10 and 11 plot too far apart in spite of being situated quite close in the White Mfolozi River. Another example: Komati River Site 55 seems to lie too high and Site 57 lies too low. The respective stage discharge calibration curves ought to be checked.

6.2 Flood wave propagation

In Figure 6.4 the time of peak was plotted against distance from origin for major rivers where sufficient information could be gathered to define an approximate propagation diagram. At sites where stage hydrographs were recorded the time of peak was determined from the chart. At many stations the hydrograph was multi-peaked. Care was taken to identify the corresponding flood waves as they propagated downstream. For this reason the time of peak shown in the diagram does not always agree with the time listed in Column 14 of Appendix 2. The rest of the data were obtained from local inhabitants and should therefore be considered as less accurate. With the exception of the upper reaches of the rivers these subjective time estimates were on the whole in reasonable accord. Distances from the river source were measured on 1:50 000 scale maps.

In spite of the abovementioned difficulties Figure 6.4 provides valuable information on expected flood wave propagation speeds and could be used for less accurate flood warnings in the region. The diagrams reveal the following:

- Flood peak times increase from north to south which corresponds to the general advancement of cyclone Domoina.

- The speed of flood wave propagation is roughly proportional to the relative magnitude of the peak (expressed by the Francou-Rodier 'K') and the river slope as long as flood plain storage is negligible. The maximum speeds occurred in certain reaches of the Pongolo and Mfolozi Rivers and reached ~ 25 km/h.

- Markedly decreased slope and flood plain storage resulted in a sharp decrease of propagation speed. Example: Komati River downstream of the Swazi border, Mfolozi River downstream of the confluence of the White-Black Mfolozi. In these reaches the speed was less than 5 km/h.

- Note that the Black Mfolozi peaked about 6 to 7 hours before the White Mfolozi. (The time-lag corresponds to the north-south movement of the cyclone). Consequently Site 19 (N2 road bridge near Mtubatuba) experienced a multiple peak type - or a very flat-topped hydrograph. It is indicative that the time of peak estimates of the inhabitants varied in the wide range of 19h00 to 24h00, 31 January.

7. EROSION AND SEDIMENTATION

In this chapter the results of various surveys and investigations are briefly described. The problems are not directly connected, but all are believed to be important for hydrologists and engineers.

7.1 Interpretation of pre- and post Domoina LANDSAT images

(Contribution by U. Looser, Hydrological Research Institute, Department of Water Affairs).

The interpretation of pre- and post flood LANDSAT images concentrates on the following selected areas:

1. Pongolo River catchment: comprising the area between longitudes 31°28'E and 32°08'E.

2. Black Mfolozi catchment above the weir W2M06. The position of the gauging station is 28°04'S, 31°33'E.

3. Mfolozi catchment east of longitude 31°50'E.

The following LANDSAT images at the scale of 1:250 000 were used:

Scene ID 40413-07194,	2 September '83	for areas 1 + 2
Scene ID 40637-07165,	13 April '84	for areas 1 + 2
Scene ID 40342-07142,	23 June '83	for area 3
Scene ID 40630-07113,	6 April '84	for area 3

7.1.1 Pongolo River catchment (Figure 7.1a, Photo 53)

The Pongolo River catchment between longitudes 31°28'E and 32°08'E covers an area of 2 609 km^2. The northern and north-western parts of this area are situated in Swaziland. The Pongolo River is impounded by the Pongolapoort Dam which is situated in the Lebombo mountains. East of the Lebombo mountains there is a small part of the Pongolo flood plain situated within the sample area.

(i) Land erosion

Over 250 km^2 (approximately 10% of the area) are severely overgrazed. These areas can be clearly seen on the pre flood image, because they appear white. It is assumed that much of the land erosion during the Domoina flood occurred in this area. Sheet, rill and to a smaller extent gully erosion appear to have been the most important erosional processes. On the post flood image the overgrazed areas are still easy to identify: they appear as light blue and red coloured areas. The light blue is the reflection of wet soil and the red indicates patches of green vegetation after the good rains.

(ii) Widening of river channels

On the post flood image the river channels are very well defined in comparison to the pre flood image. The high erosive power of the floods were responsible for streambank erosion which resulted in river channel widening. This is especially the case for the area west of the Pongolapoort Dam.

(iii) Sediment deposits in river channels and on cultivated areas

No significant sediment deposits in river channels or on cultivated areas could be seen on the post flood image. It would seem that most the sediment was trapped in the Pongolapoort Dam. The light blue colour of the dam on the post flood image indicates the high sediment content of the water. Low sediment containing water appears as dark blue or black as is clearly shown on the pre-flood image.

(iv) Changes in riverine and irrigated vegetation

Due to the high flood waters most of the riverine vegetation was washed away, especially in the area above the Pongolapoort Dam. These areas adjacent to the river were cleared of vegetation leaving only bare soil and sand (white reflection). This is possibly why the river channels are so well defined on the post flood image. On this image a significant increase in irrigated areas can be seen - especially surrounding the village Pongola.

(v) Changes in vegetation cover over the catchment generally

On the post flood image the whole area is covered with new vegetation (reddish colour). Even the severely overgrazed and eroded areas appear as this colour, indicating the recovery of the veld after the good rains.

7.1.2 Black Mfolozi catchment (Figure 7.1b, Photo 54)

The catchment above the weir W2M06 (Site 16) comprises the headwaters of the Black Mfolozi. It covers an area of 1 648 km^2. It is a mountainous catchment with altitudes ranging from 250 m to 1 600 m. In the northern and western part of this area patches of forest exist.

(i) Land erosion

Out of the three selected areas this catchment shows the worst erosive flood damage. Approximately 36% (600 km^2) of this area is bare soil according to the pre flood image. It can therefore be assumed, that a large amount of sediment was transported from these areas into the main river channels and out of the catchment. Severe sheet and rill, as well as gully erosion must have been the main processes during the cyclonic rainfall as there was no vegetation protecting this bare soil. On the post flood image these badly damaged areas are clearly distinguishable, due to the light blue reflectance of the wet soils. These areas on the image are slightly blurred by the red colouration indicating limited recovery of vegetation after the good rains.

(ii) Widening of river channels

It can be clearly seen that river channel widening was characteristic everywhere in this catchment. The gradients of the rivers in this area are steep, therefore floods which had a very high erosive power necessary for streambank erosion and channel deepening had the potential to significantly alter channel geometry. As a result the river channels are all well defined on the post flood in comparison to the pre-flood image.

(iii) Sediment deposits in river channels and on cultivated areas

Sedimentation can not be excluded totally in the river channel, especially on the inside of river bends and where the river flooded flat areas next to the channel. This sedimentation took place mainly during the latter stages of the flood. However, these sediment deposits are negligible compared to the amount of sediment which was exported from the catchment. There is no indication of sediment deposition on cultivated areas.

(iv) Changes in riverine and irrigated vegetation

Due to the widening of river channels and the flood waters breaking the river banks a large amount of riverine vegetation was washed away. Damage to irrigated vegetation was not observed.

(v) Changes in vegetation cover over the catchment generally

The post flood image shows a clear recovery of the vegetation in the whole catchment. Only in the severely overgrazed and damaged areas (which are easily distinguishable on the pre-flood image) did poor vegetation recovery take place. Large areas of bare soil still remain. These appear as a light blue colour on the post flood image.

7.1.3 Mfolozi catchment (Figure 7.1c, Photo 55)

The Mfolozi catchment east of longitude 31°50'E covers an area of 1 580 km^2. The western part consists of hilly land. The Mfolozi Game Reserve is situated west of the confluence of the White and Black Mfolozi. The eastern part consists of the Mfolozi flood plain and includes large cultivated areas. Large areas of afforestation also exist.

(i) Land erosion

The white patches on the pre flood image indicate that 19% (300 km^2) of that catchment is severely overgrazed and damaged. It can be assumed that the worst erosion occurred in this area.

(ii) Widening of river channels

Widening of river channels took place mainly in the western part of the catchment. The well defined river channel on the post flood image shows this clearly.

(iii) Sediment deposits in river channels and on cultivated areas

A considerable amount of sedimentation took place in the Mfolozi flats. On the post flood image approximately 90 km^2 of sediment deposition can be seen. These sediments cover one third (about 60 km^2) of the cultivated areas on the Mfolozi flood plain.

As the flood waters subsided sedimentation also occurred in the river channel downstream of the confluence of the White and Black Mfolozi. This is shown by the easily visible white areas adjacent to the river channel on the post flood image. However, there was considerable net-erosion in the main channel as proved by the comparison of pre- and post flood surveys of cross-sections at Site 18 (see Chapter 7.4).

(iv) Changes in riverine and irrigated vegetation

A significant change in riverine and irrigated vegetation took place. The riverine vegetation was washed away on the banks of the White and Black Mfolozi. Downstream of the confluence of these rivers the riverine vegetation was buried under sediment deposits. Approximately 60 km^2 of irrigated land on the Mfolozi flood plain was also buried under sediment deposits. About 7,5 km^2 of irrigated lands were still standing under water on 6 April, two months after the flood. Approximately 38% of the total cultivated area in the Mfolozi flood plain was destroyed by the Domoina flood.

(v) Changes in the vegetation cover over the catchment generally

Apart from the destroyed flood plain and the areas in the vicinity of the main river channels the vegetation appears to have recovered fairly well. However, large areas which were overgrazed and damaged by erosion still do not have the necessary vegetation cover to protect the soil from further erosive events.

7.2 Comparison of surveyed and equilibruim cross-section in alluvial river channels

The purpose of the comparison has been to reveal possible systematic over- or underestimation of flood peaks calculated from slope-area surveys in erodible river channels. The comparison consisted of plotting surveyed cross-sections against those that would be required to maintain dynamic equilibrium (i.e., neither deposition, nor erosion in spite of heavy sediment transport) for the flood peaks calculated from the surveyed sections. The equilibrium sections were calculated by two empirical methods:

(i) the Simons-Albertson method [20]; and

(ii) the Ranga Raju method [21].

In the calculations only the data of the main channel were used in order to comply with 'erodible conditions'.

(i) Simons-Albertson equation (1960)

These were based on Indian and North American data and included the influence of bed and bank material and also of bed material concentration. The eight selected SA sites belonged to the 'sand-bed with cohesive banks at heavy sediment load' category for which the authors have established the following equations:

mean depth: $h_o = 0,61 + 0,348\ Q^{0,36}$ (m)

mean width: $B_o = 2,77\ Q^{0,5}$ (m)

mean velocity: $V_o = 5,49\ Q^{0,209}\ S^{0,29}$ (m/s)

The equilibrium cross-section was then computed as the mean value of

$A_o^{1} = h_o \times B_o$ and $A_o^{11} = Q/v_o$

(ii) Ranga Raju resistance relations (1970)

This empirical method is based on worldwide laboratory and prototype data and, according to the author, predicts the equilibrium velocity within 30% accuracy for 90% of those data. The necessary information is the following: hydraulic radius, water surface slope, median sediment diameter and specific weight of water and sediment. From the equilibrium velocity the equilibrium cross-section was obtained as $A_o = Q/v_o$.

The surveyed and calculated cross-sections and median sediment diameters are listed in Table 7.1. In Figure 7.2 the sediment sample grading curves are shown. In Figure 7.3 the calculated equilibruim areas are plotted against the surveyed cross-sections.

TABLE 7.1: COMPARISON OF SURVEYED AND EQUILIBRIUM CROSS-SECTIONS

Site No.	River	Sediment size d_{50}(mm)	Surveyed Area A (m^2)	Equilibrium area A_o (m^2)		
				Simons Albertson	Ranga Raju	Mean
8	Mhlatuze	0,20	496	575	458	516
13	White Mfolozi	0,38	2 100	1 685	3 500	2 590
17	Black Mfolozi	0,12	2 677	2 310	3 870	3 090
18	Mfolozi	0,40	6 040	3 730	8 490	6 110
29	Pongolo	0,22	2 245	2 120	2 300	2 210
48	Great Usutu	0,85	4 208	2 777	5 500	4 140
56	Komati	1,33	1 105	847	1 225	1 040
61	Komati	0,21	1 178	919	2 200	1 560

It is seen that the two methods give very different results, but their mean value is similar to the surveyed area. In principle the Ranga Raju method is more flexible and accurate because it includes more independent variables and was founded on a much larger data-base. However, median sediment diameters d_{50} were obtained at each site only from one or two bed surface samples and might not be sufficiently representative.

The conclusion from Figure 7.3 is, keeping in mind the inherent shortcomings, that agreement between practice and theory is acceptable i.e., the surveyed flood peaks do not suffer from systematic errors.

7.3 Sedimentation in the Pongolapoort Dam

The quick, provisional reservoir bed survey carried out after the Domoina floods (but before the moderate February 1985 flood) was limited to only eight cross-sections. It, nevertheless, supplied sufficient information for an approximate estimation of the sediment volume deposited in the dam since its completion (1970). Figure 7.4a shows the plan of the dam with the position of the sections. Figure 7.4b shows the longitudinal section of the bottom in 1955 and after Domoina. This section runs along the original thalweg of the river. The depth of deposits is very impressive: it varies between 6 and 18 m. Figure 7.4c shows the cross-sections (looking downstream). The narrow sections (1, 4, 5 and 6) and the wide ones (2, 3, A and B) are grouped together.

The total sediment volume estimated from the survey is $\sim 125 \times 10^6\ m^3$. It can be safely assumed that by far the largest part was deposited by Domoina as there were no important floods between the completion of the dam wall and 1984. From Column 16 of Appendix 2 the total flood volume is $2\,105 \times 10^6\ m^3$ (Site 32) which means that the sediment concentration was 5 to 6%.

Other observations

- In the main reservoir the deposits were concentrated in the former river channel.
- In the gorge the deposits were more evenly spread.
- At the two ends of the main reservoir (Section A and B) and also along the right bank of the entrance to the gorge (Sections 4 and 5) sedimentation was negligible. It seems, rather, that along Sections A and B some erosion took place, except for the localised depositions brought in by the tributaries.

7.4 Cross-section changes in the Mfolozi River

The problem is dealt with in more detail in reference [22].

7.4.1 Natural river reaches

After the February 1977 floods slope-area surveys were carried out at three sites in the alluvial valleys of the Mfolozi catchment. The same sites were resurveyed after Domoina with the double aim of flood peak determination and checking of cross-section changes. The sites were the White Mfolozi in the Umfolozi Game Reserve (Site 13), the Black Mfolozi in the Umfolozi Game Reserve (Site 17) and the Mfolozi 6 km upstream of the N2 road bridge crossing (Site 18). At each site four cross-sections were surveyed. The results are plotted in Figure 7.5 (a - c). For a simple numerical comparison the following parameters were used:

P_{VOL} = total Domoina rainfall volume over catchment
Q = flood peak
S = slope of flood line
V = mean velocity in main channel
d_{50} = median sediment diameter
$\Delta A = A_{84} - A_{77}$ = increase in total wet cross-section
a_e = eroded area
$\Delta h = h_{84} - h_{77}$ = increase in maximum water depth
y = maximum depth of erosion relative to the February 1977 channel bed
x = width of erosion at the February 1977 flood level

The numerical comparison is summarised in Table 7.2. Parameters are averages from four sections except d_{50} which was determined from only one or two samples at each site.

TABLE 7.2: COMPARISON OF CROSS-SECTION ENLARGEMENTS IN THE MFOLOZI RIVER

Item No.	Parameter	Unit	White Mfolozi Site 13	Black Mfolozi Site 17	Mfolozi Site 18
1	P_{VOL}	10^6 m^3	2 130	1 970	4 610
2	Q	m^3/s	6 500	10 000	16 000
3	S	-	0,0010	0,0012	0,00056
4	V	m/s	3,1	3,6	2,8
5	d_{50}	mm	0,39	0,12	0,40
6	ΔA	m^2	1 820	2 270	5 290
7	a_e	m^2	337	189	1 180
8	$a_e/\Delta A$	-	0,19	0,06	0,22
9	Δh	m	9,7	12,1	11,7
10	y	m	1,3	1,1	2,0
11	$y/\Delta h$	-	0,13	0,09	0,17
12	X	m	35	17	95
13	X/y	-	27	16	48

Some conclusions

(i) In absolute and relative terms the largest erosion took place in the Mfolozi (Site 18) in spite of smaller slope and lower velocities. The river banks at this site are less vegetated, thus more exposed to erosion, than at the two other sites (Compare Photo's 15, 9, 13).

(ii) In absolute and relative terms the smallest erosion occurred in the Black Mfolozi in spite of the steepest slope and highest velocities. The vegetation on the banks is similar to Site 13. The greater stability of the Black Mfolozi channel is mainly due to the following:

- erosion was restricted by scattered rock outcrops (Photo 14)
- its channel had been adjusted to relatively high floods because of steep, less elongated and more impermeable catchment
- sediment concentration must have been extremely high during the Domoina flood owing to very severe land erosion of the bare soil, particularly in the upper catchment (Figure 7.1b, Photo 54). This in turn means that relatively less energy was left for channel scour.

The comparison of Items 1 and 7 in Table 7.2 suggests that the channel erosion was correlated to the total rain volume, in other words: to the volume and duration of the flood, rather than to the peak.

(iii) The lateral erosion i.e., the widening of alluvial channels appears to have been far more important than vertical erosion, compare Items 10, 12 and 13 in Table 7.2.

(iv) The comparison of the difference of maximum water depths (Δh) and scour depth (y) indicates that the latter was relatively small. This means that increasing flood discharges were mainly accommodated by rising water surface and not by deepening river bed.

It is noted that in March 1985 at Site 18 Piezometer Cone Penetration Testing with pore pressure recording (CUPT) was carried out to determine the deepest scoured line during Domoina [22]. The tests revealed that this line was only 1 to 4 m below the surveyed post Domoina profile and was mainly restricted to the middle of the main channel.

(v) Photo 17 shows the erosion of a steep sand bank at Site 18. The loose sand at the toe of the steep face is evidence of lateral channel erosion during flood recession when the thoroughly wetted banks collapse because of increased weight and decreased frictional strength. This means, in turn, that the top width of the surveyed post flood cross-section had to be wider than the top width during flood peak.

Deposition of suspended sediment took place during the falling flood stage, mainly at Site 18 (Photo 55). The deposits were characteristic only in those parts of cross-sections where the velocity was low or the flow was stagnant. Such parts are the floodplain, ridges in the main channel and sudden widenings at lateral inflows. The depth of sediment deposits over flood plains was generally in the order of 0,5 m or less (Photo's 9, 13, 14, 15, 16).

7.4.2 Contracted section at the N2 road bridge crossing (Site 19, Photo's 19, 20)

In Figure 7.6 three surveyed cross-sections are shown (looking downstream). The dotted line was surveyed in the early sixties before the building of the bridge which was washed away by Domoina. This section represents natural (= unrestricted) flow conditions. The dashed line was surveyed just after the large flood which occurred in July 1963 during the early stages of the bridge construction. This flood peak was estimated as ~ 8 500 m^3/s and is the second largest on record after Domoina. The dashed line also represents mainly natural flow conditions because at the time of the flood only temporary structures were constructed and the long northern approach embankment was not yet built. Both sections appear in reference [12] and are reproduced with the author's permission. The continuous line was surveyed after Domoina and represents constricted flow conditions.

The conclusion from Figure 7.6 is essentially the same as for the natural sections shown in Figure 7.5: erosion took place chiefly laterally. It is seen that the post Domoina channel bed is only ~ 2 m deeper than the pre 1963 one. The lateral erosion during the July 1963 flood had been in the order of 50 m and it was increased by a further 50 to 100 m during Domoina.

The deepest general scour line during Domoina is unknown. However, in view of the CUPT soil probing results 6 km upstream (Site 18) which have indicated only 1 to 4 m difference between the surveyed and the deepest scour lines (Chapter 7.4.1), it can be safely assumed that the 10 m extra-general scour used for flood peak estimation (Chapter 5.1.2) was very conservative.

Photo 20 is an aerial view of the Mfolozi River taken after Domoina. It shows the destroyed road and railway bridges and the extensive sediment deposition which is particularly impressive downstream of the latter bridge site.

8. SUMMARY OF RESULTS

Survey

- Rainfall at more than 450 points
- Flood measurements in 45 rivers
- Flood peaks at 85 sites
- Flood hydrographs at 40 sites
- Sedimentation survey in the Pongolapoort Dam
- Erosion survey in the Mfolozi River

Rainfall

- It was the highest in living memory over large areas of Swaziland, South Eastern Transvaal and Northern Natal
- The total duration of the rainfall was 5 days. At most points more than 90% of the rain fell in three days
- The highest point rainfalls exceeded 900 mm. Over 47 000 km^2 more than 400 mm rain fell
- In parts of the Mfolozi, Pongolo and Great Usutu catchments the rainfall was in the order of PMP or the highest recorded 5-day rainfalls in Madagascar
- The Eastern Escarpment has been an efficient barrier against the westward movement of heavy rain
- In terms of overland penetration and residence there is a real chance that similar events could take place within decades.

Floods

- In terms of Francou-Rodier 'K' the storm resulted in the highest flood peaks ever recorded in South Africa and, in absolute terms, some of the highest peaks as well:

  Site 14: Black Mfolozi, A = 238 km^2, Q = 2 180 m^3/s,
  Francou-Rodier K=5,27

  Site 17: Black Mfolozi, A = 3 396 km^2, Q = 10 000 m^3/s,
  Francou-Rodier K = 5,52

  Site 18: Mfolozi, A = 9 126 km^2, Q = 16 000 m^3/s,
  Francou-Rodier K = 5,55

Site 27: Mozane, A = 426 km^2, Q = 3 000 m^3/s,
Francou-Rodier K = 5,31

Site 32: Pongolo, A = 7 831 km^2, Q = 13 000 m^3/s,
Francou-Rodier K = 5,41

Site 48: Great Usutu, A = 17 974 km^2, Q = 11 300 m^3/s,
Francou-Rodier K = 4,80

- In some rivers maximum surface velocities of about 10 m/s were observed
- Surface waves of 1 to 5 m in height were observed in all the larger rivers where extreme floods occurred
- At 29 sites the return period of the flood peak was 50 years or longer
- At 9 sites the hitherto valid RMF (equivalent with Francou-Rodier K = 5,25) was exceeded
- The existing maximum flood peak regions had to be modified and a new region was established with K = 5,60
- The highest run-off percentage was around 70% and occurred in catchments of less than 1 000 km^2. The run-off percentage in the Pongolapoort Dam catchment (7 831 km^2) was 47% and the flood volume was 2 100 x 10^6 m^3
- In the Black Mfolozi and Pongolo Rivers flood peak propagation velocities reached 25 km/h.

Sedimentation and erosion

- The sediment volume deposited in the Pongolapoort Dam was in excess of 100 x 10^6 m^3
- The erosion of alluvial cross-sections in the Mfolozi River was considerable. Lateral erosion was by far the most important: at Site 18 it reached nearly 100 m relative to the pre-Domoina channel. Vertical erosion was very moderate it reached only 1 to 2 m relative to the pre-Domoina channel-bed.

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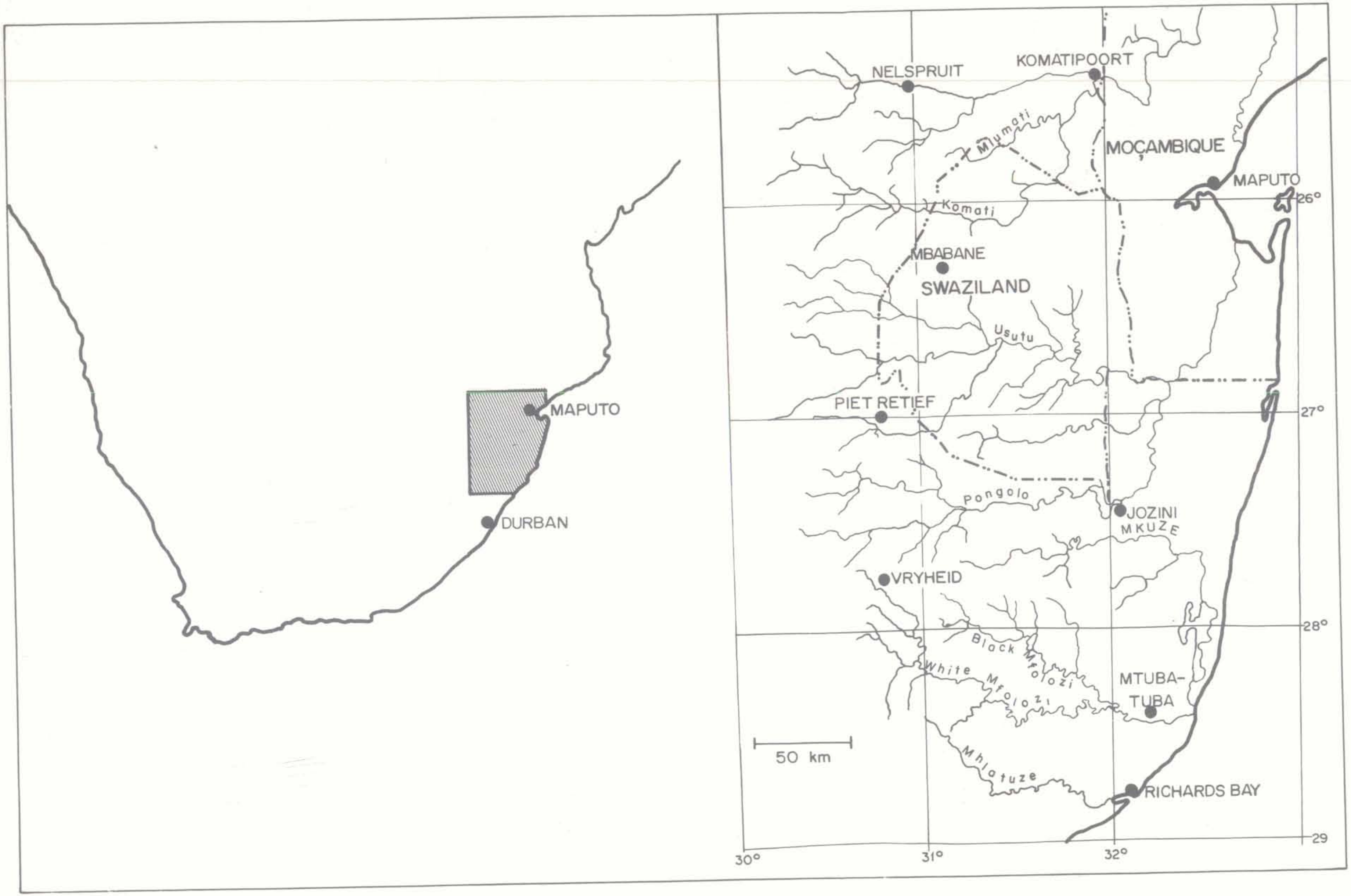


FIG. 1.1 AREA OF FLOOD DOCUMENTATION

FIG. 2.1 COURSES OF CYCLONES DOMOINA AND IMBOA

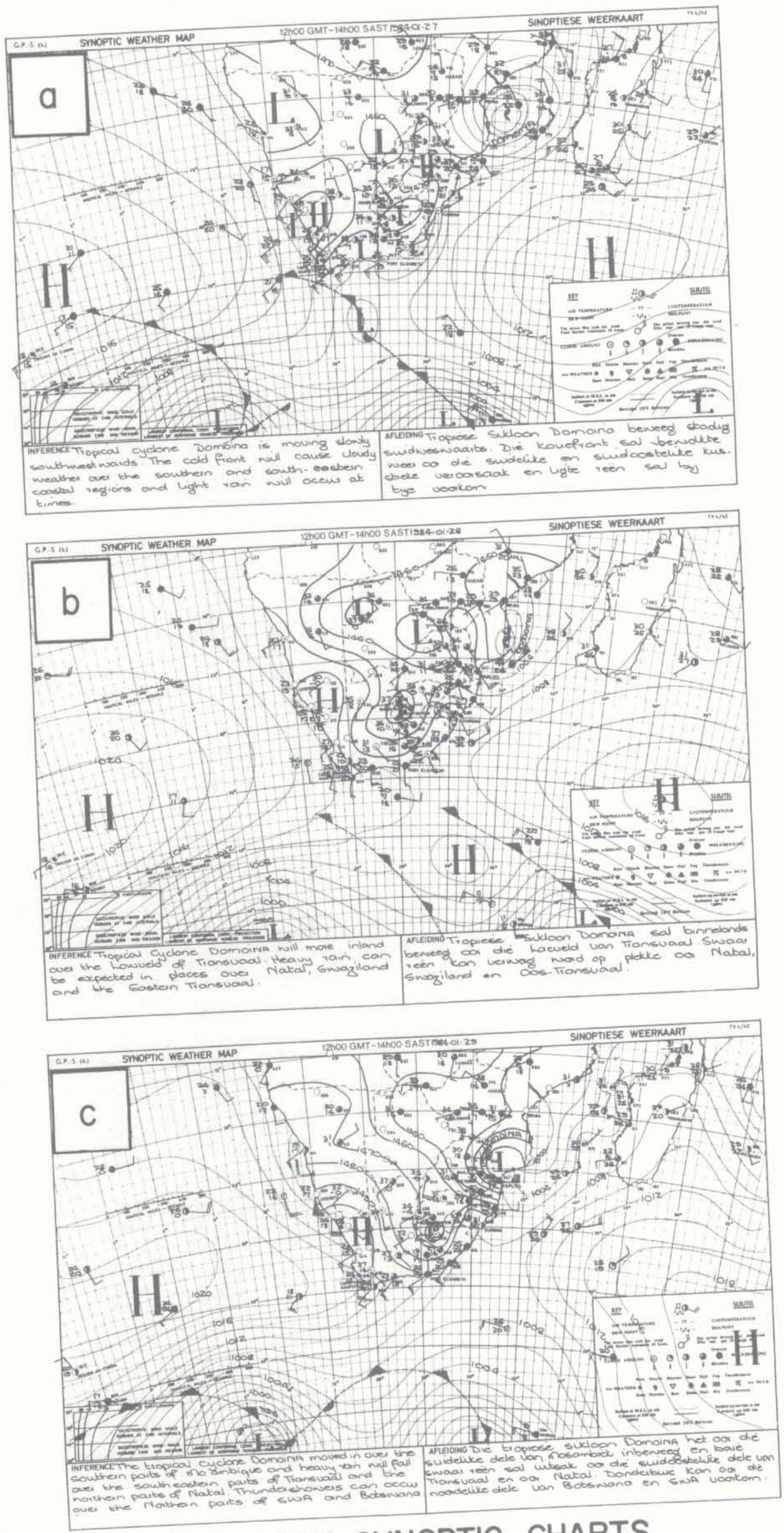


FIG. 2.2(a-c) DAILY SYNOPTIC CHARTS

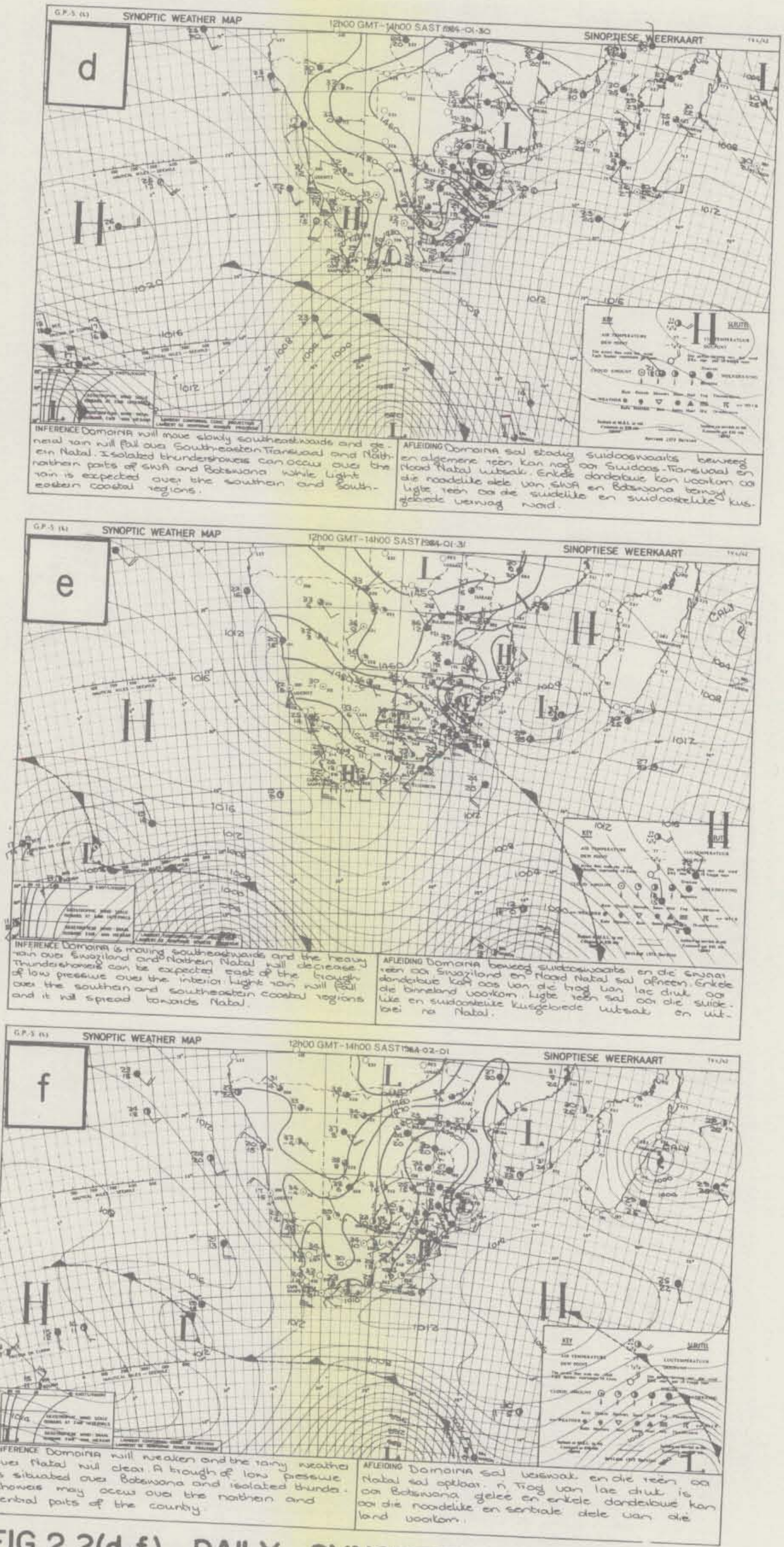


FIG. 2.2(d-f) DAILY SYNOPTIC CHARTS

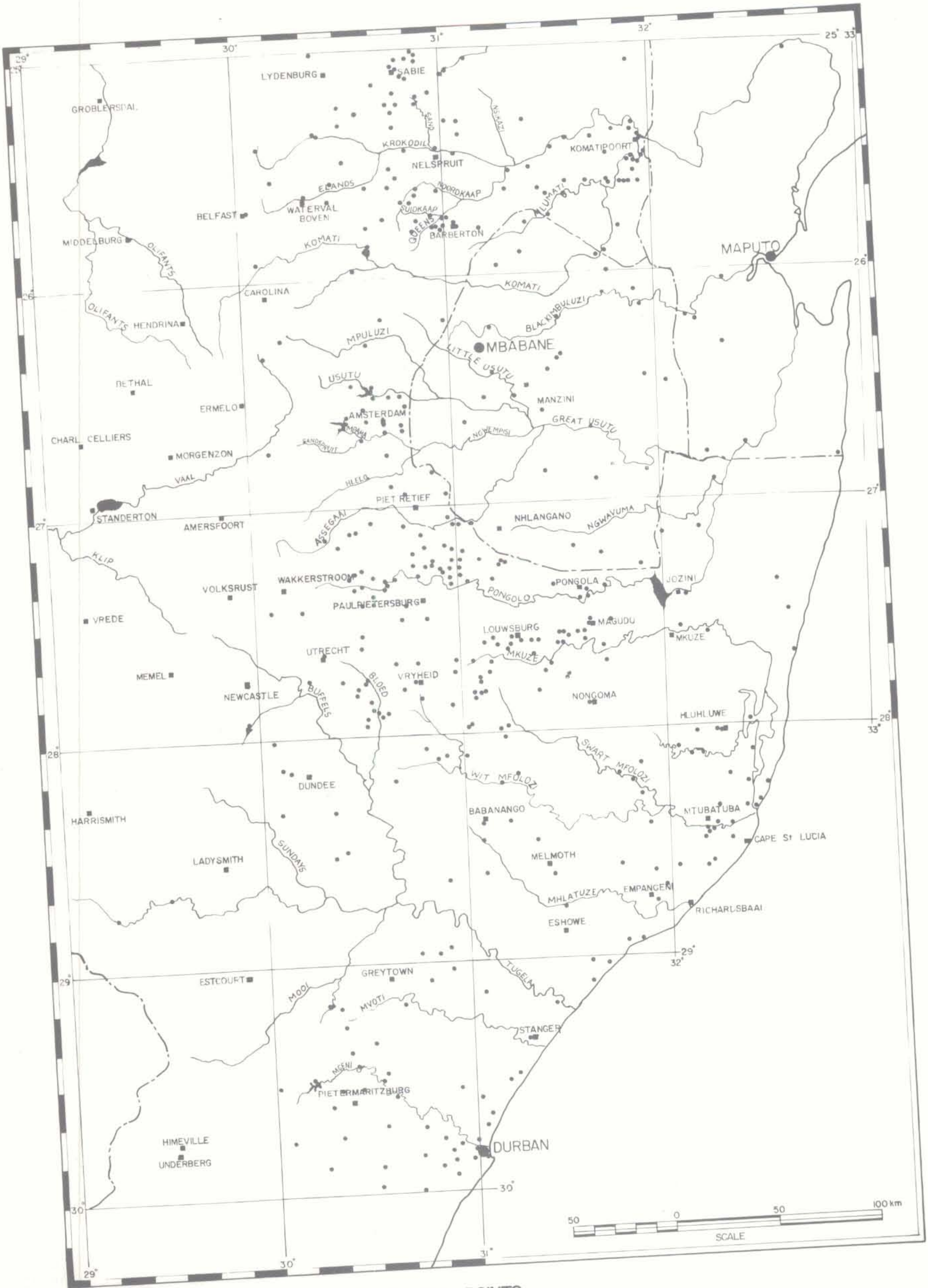


FIG. 2.3 MAP OF RAINFALL OBSERVATION POINTS

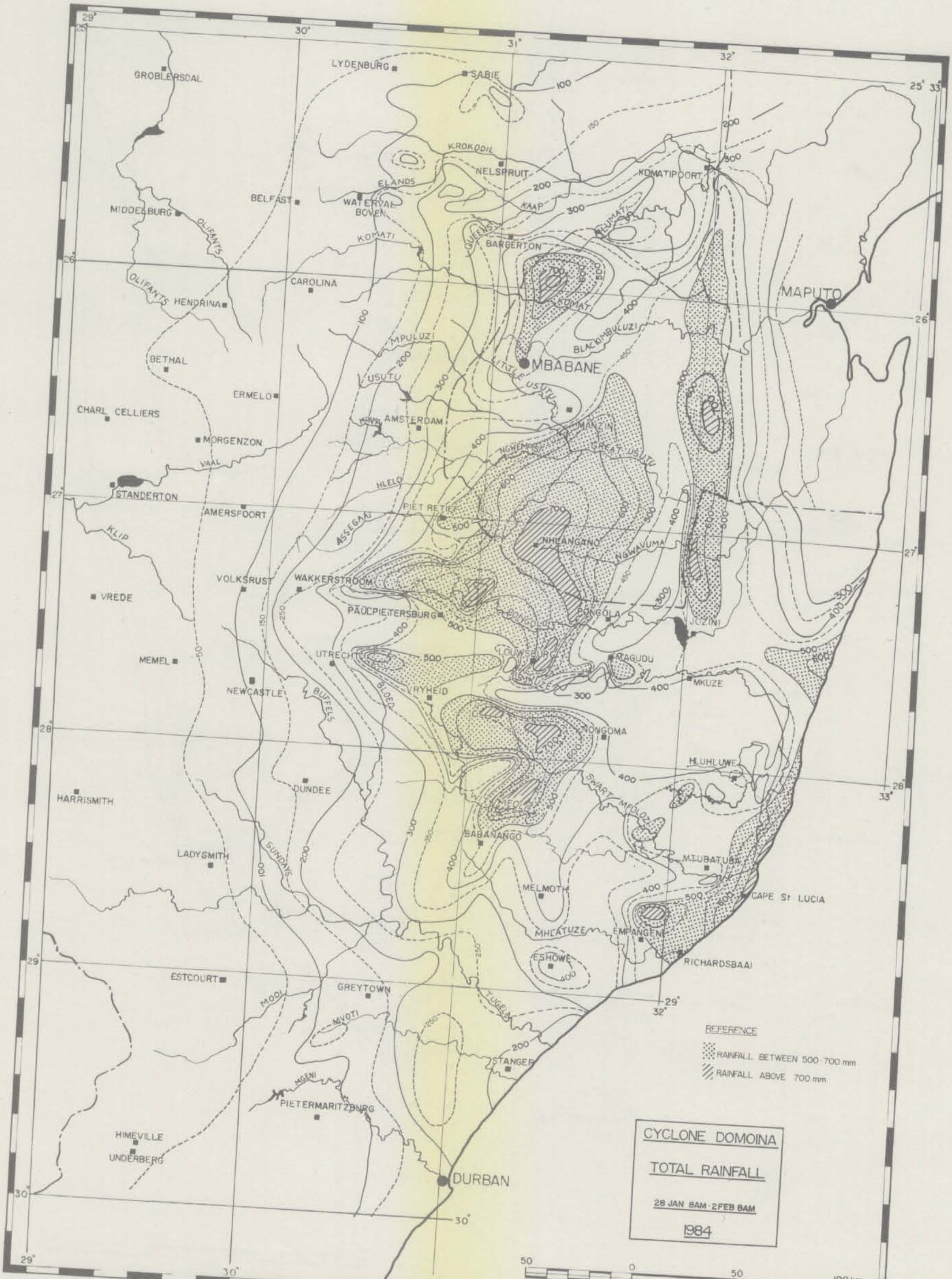


FIG. 2.4 ISOHYETAL MAP OF STORM RAINFALL 28 JAN.—2 FEB. (8 AM)

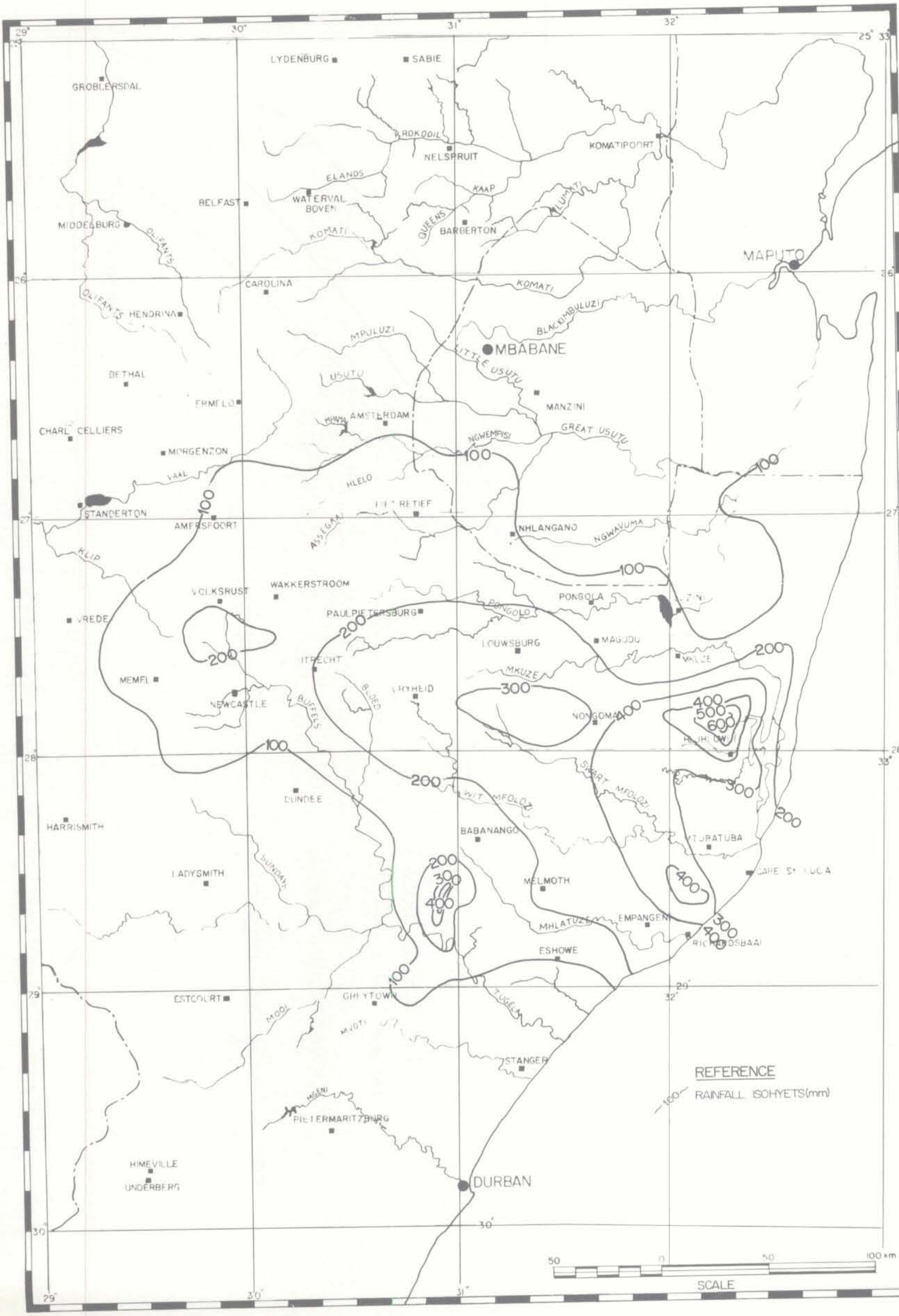


FIG. 2.5 ISOHYETAL MAP OF THE 2–5 JULY 1963 STORM

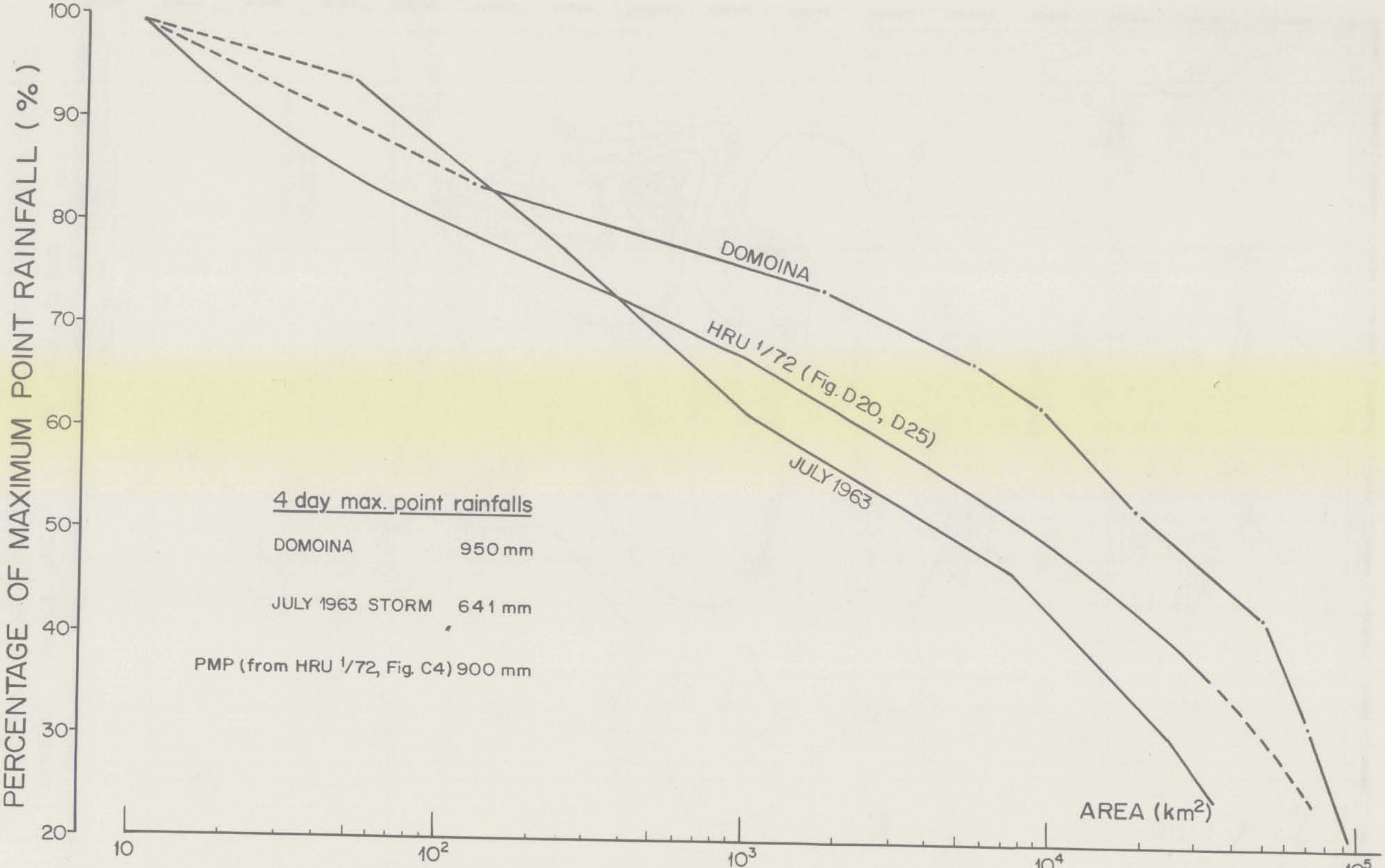


FIG. 2.6 AREAL REDUCTION OF 4-DAY MAX. POINT RAINFALLS

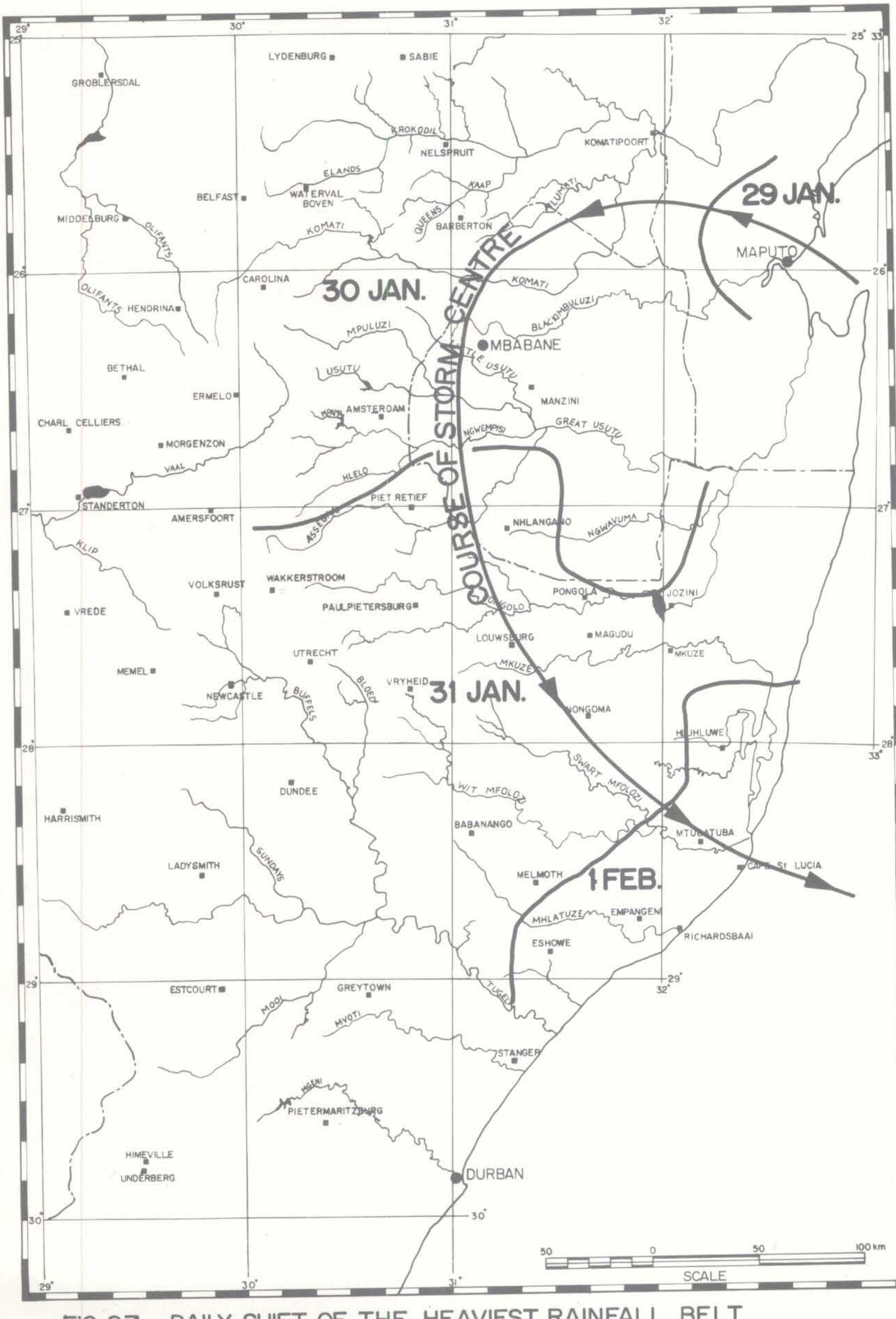


FIG. 2.7 DAILY SHIFT OF THE HEAVIEST RAINFALL BELT

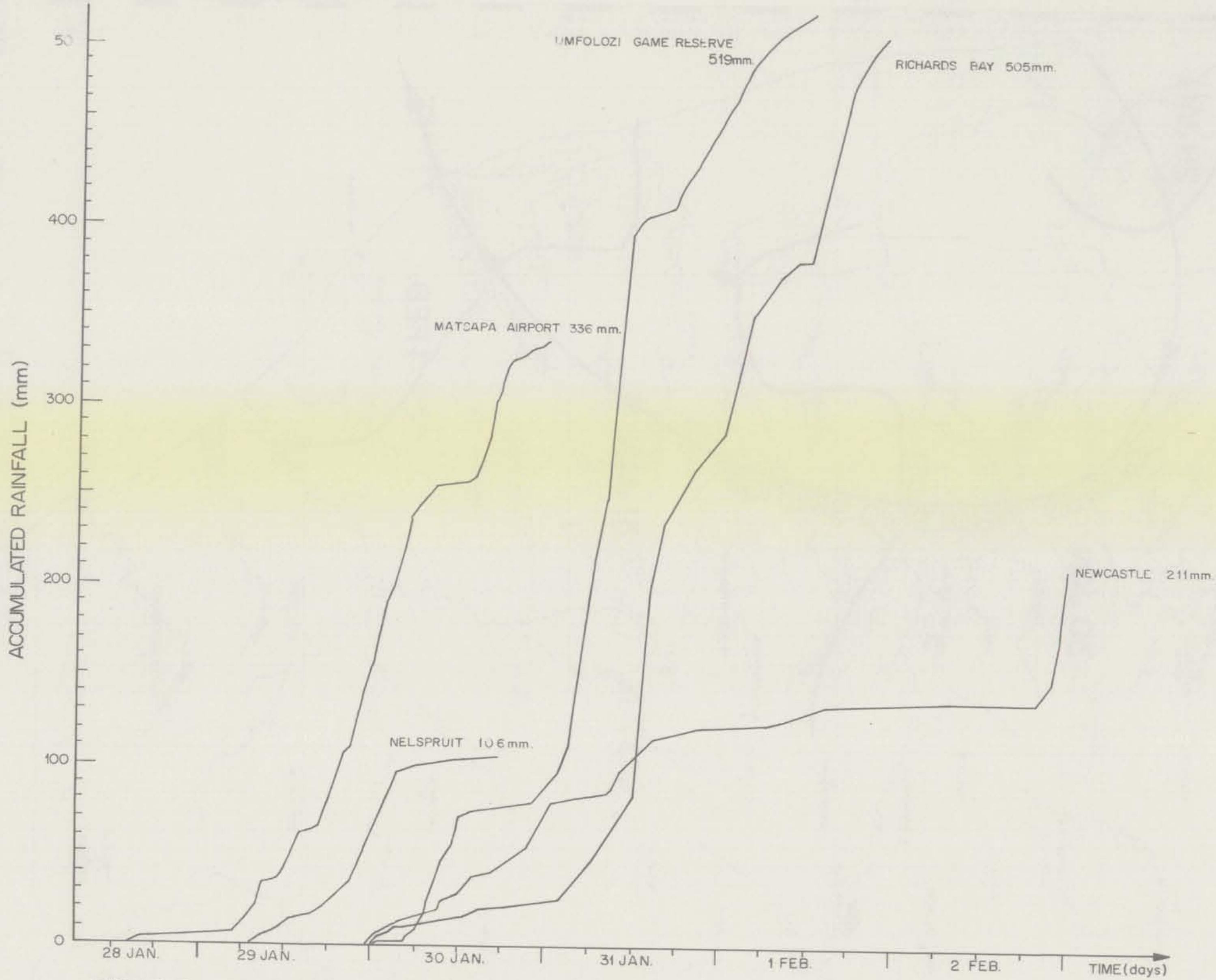
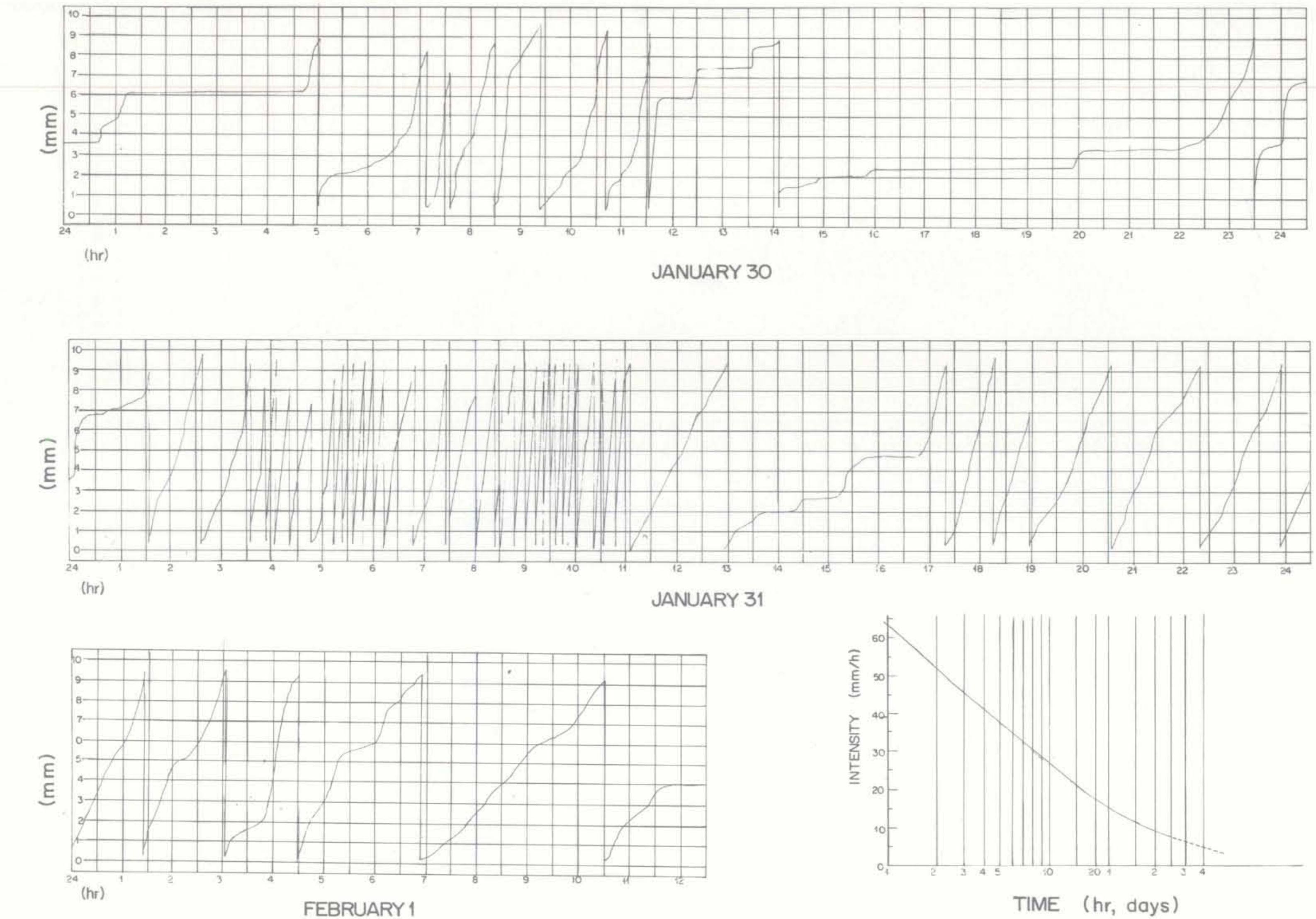


FIG. 2.8 ACCUMULATED RAINFALL AT SELECTED STATIONS



(a) PLUVIOGRAPH

(b) INTENSITY VS DURATION

FIG. 2.9 AUTOGRAPHIC RAINFALL RECORD AT UMFOLOZI GAME RESERVE

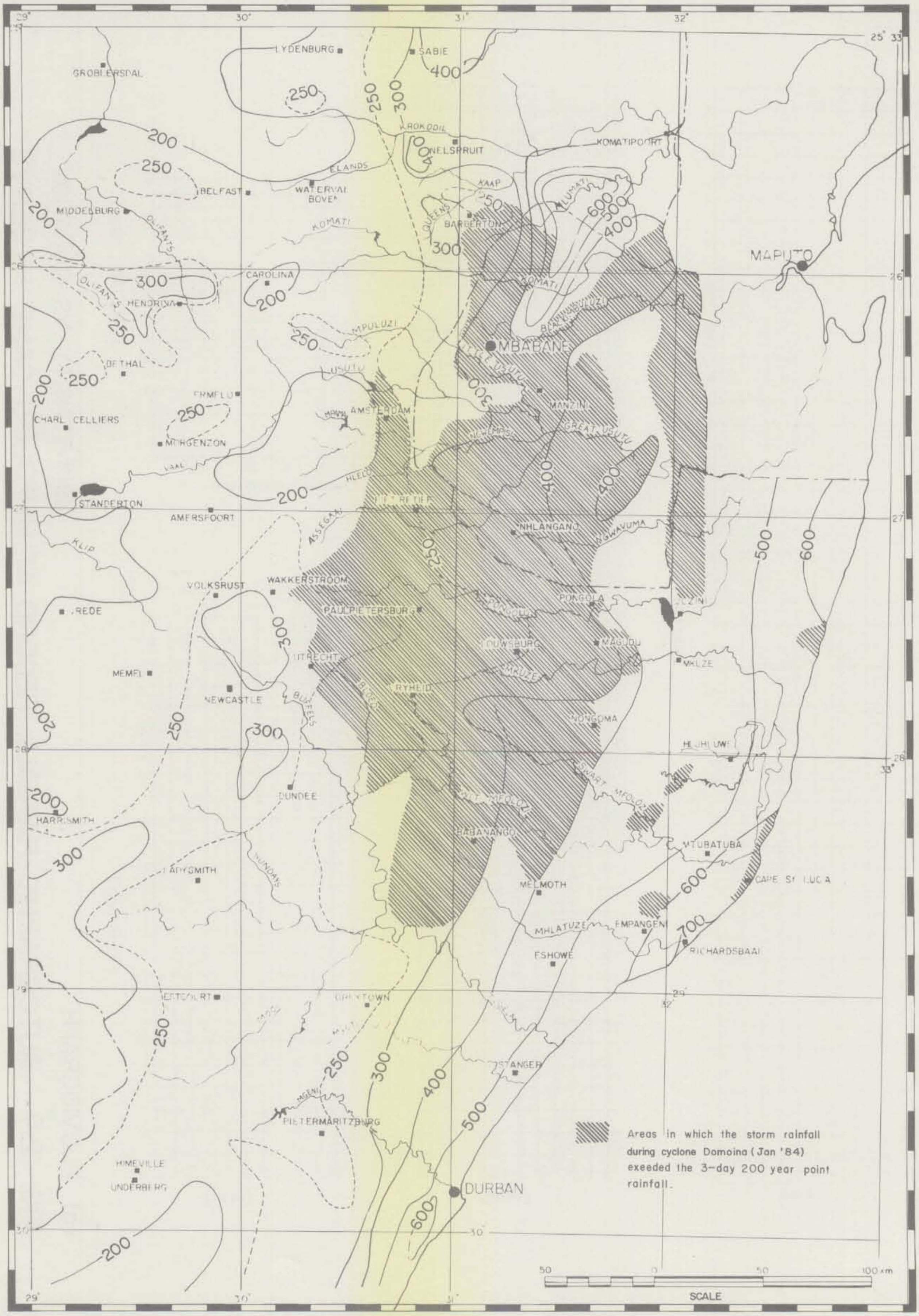


FIG. 2.10 3-DAY 200 YEAR POINT RAINFALL (based on TR 102)

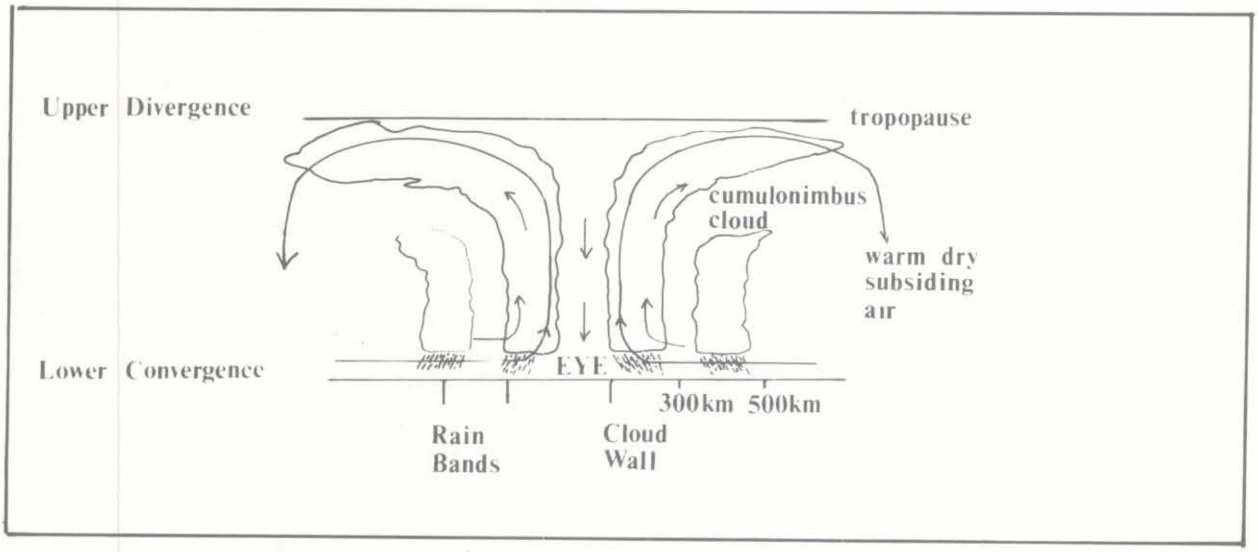


FIG.3.1a SCHEMATIC CROSS SECTION OF A TROPICAL CYCLONE

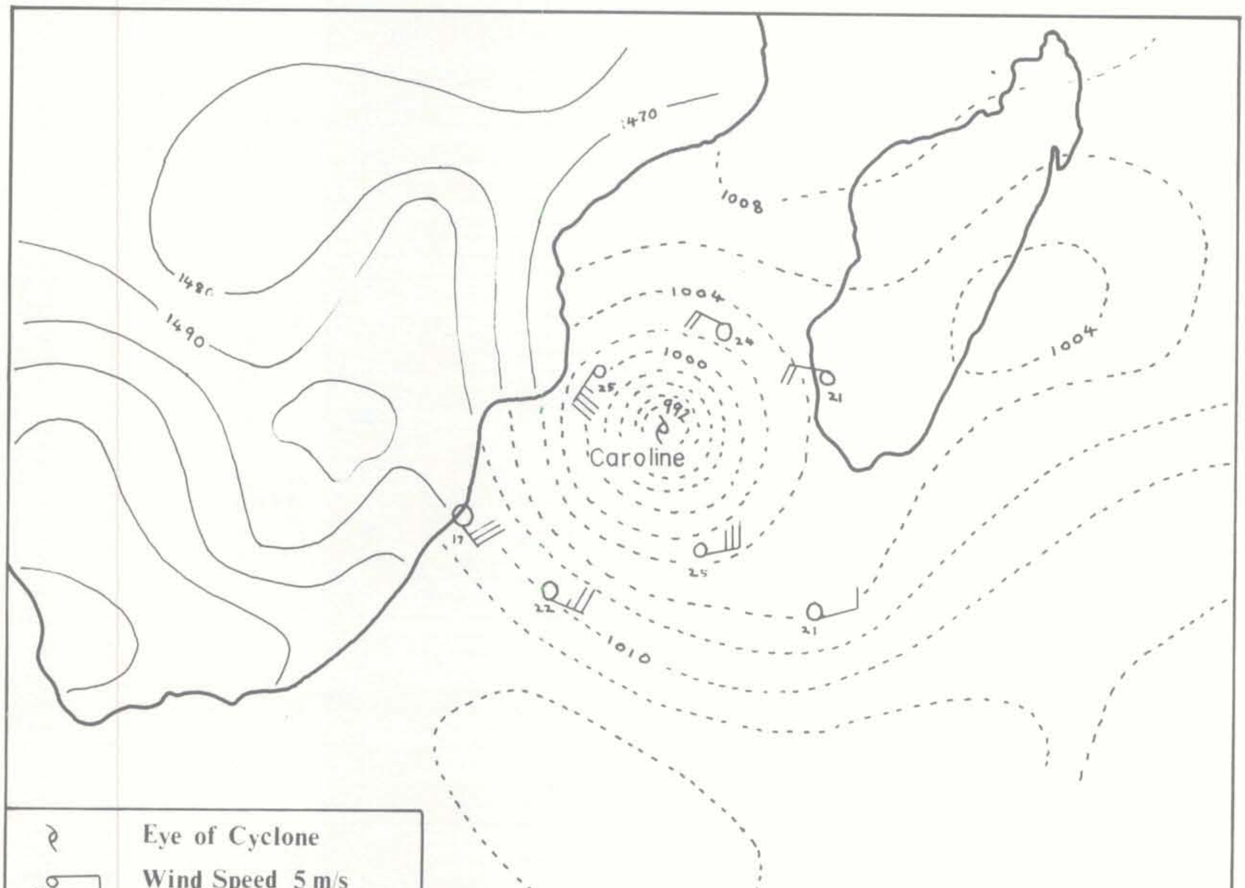


FIG.3.1b EXAMPLE OF A SYNOPTIC WEATHER MAP

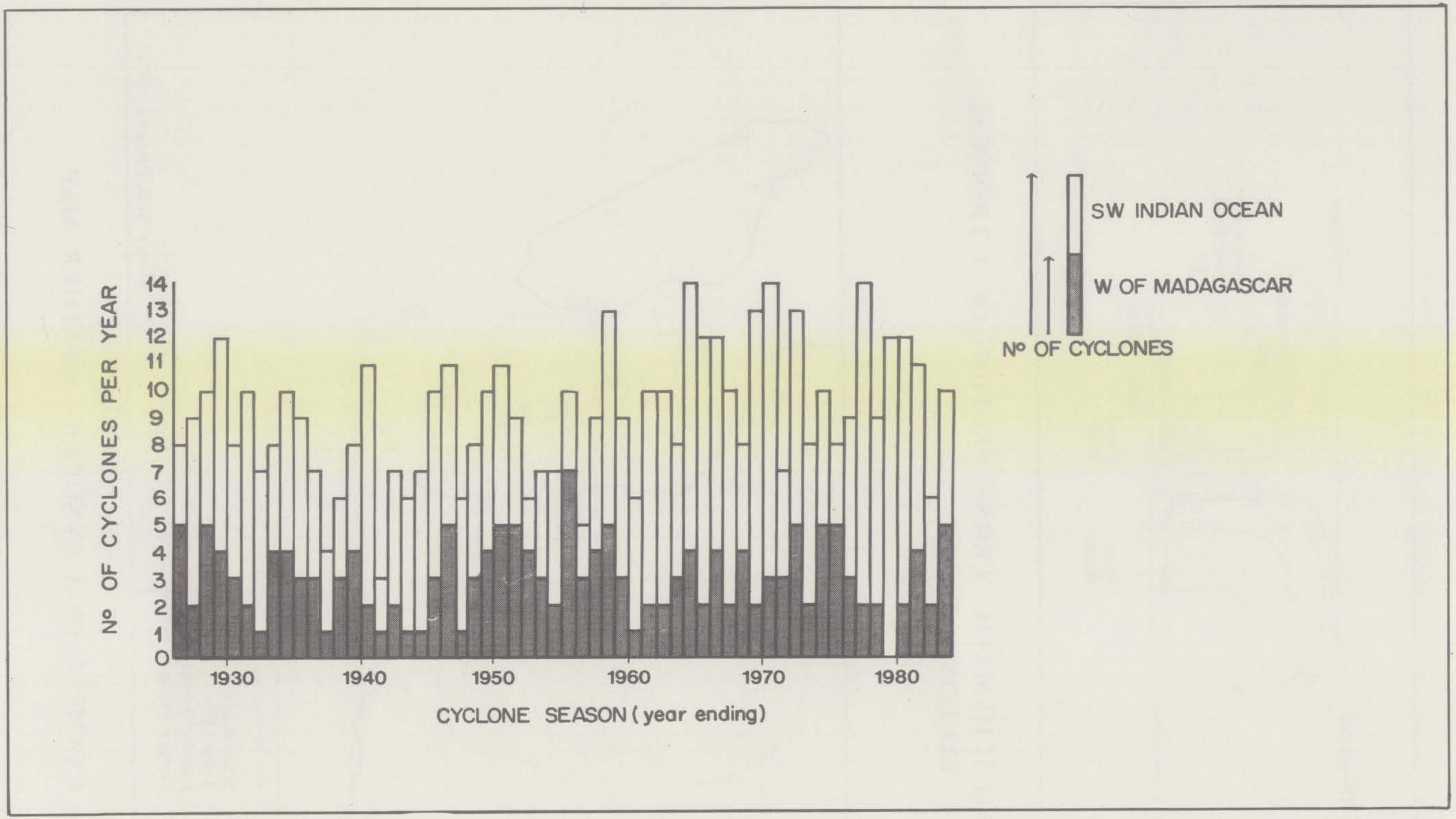


FIG. 3.2 ANNUAL FREQUENCY OF TROPICAL CYCLONES

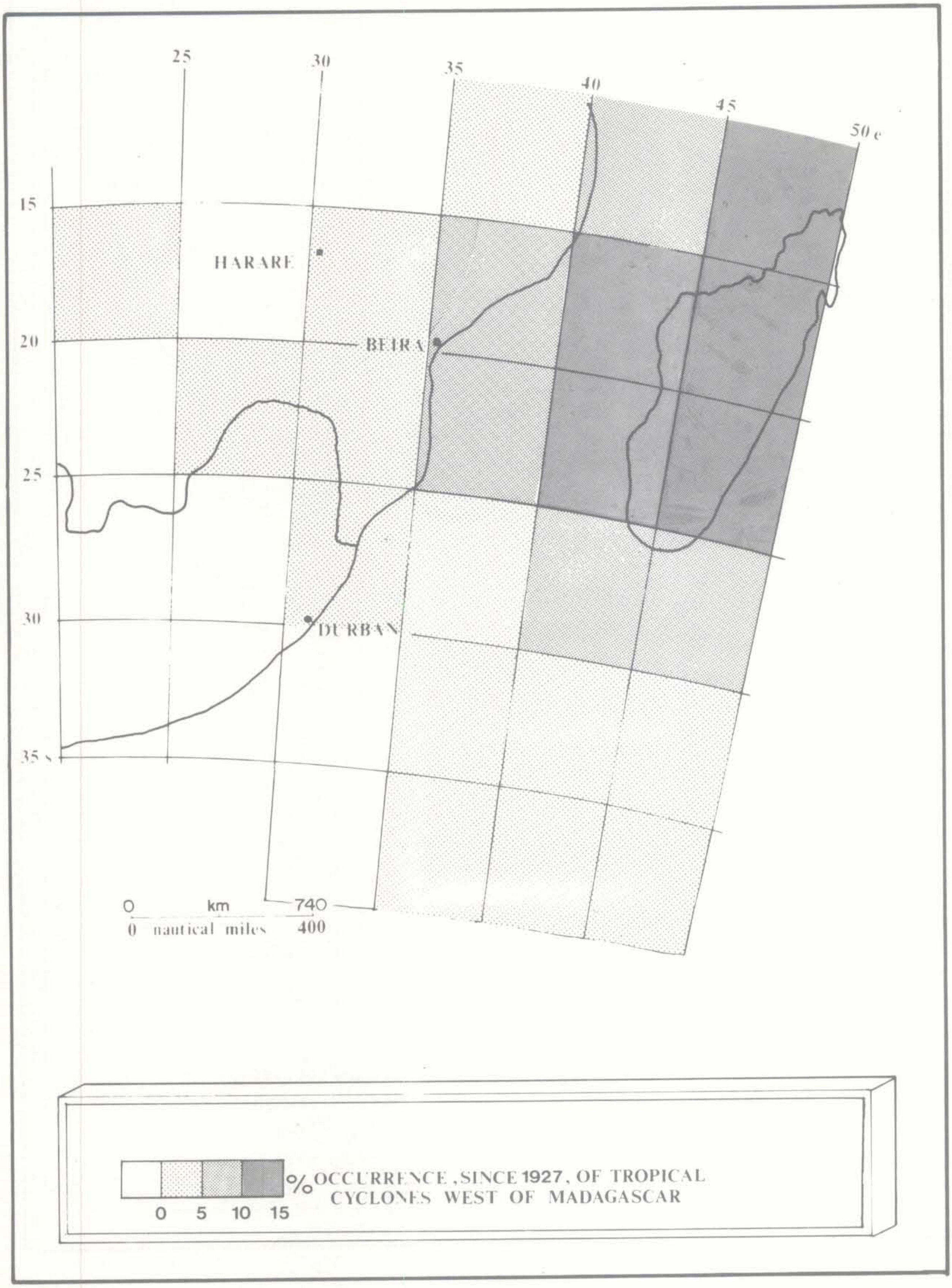


FIG.3.3 THE DISTRIBUTION OF TROPICAL CYCLONES SINCE 1927

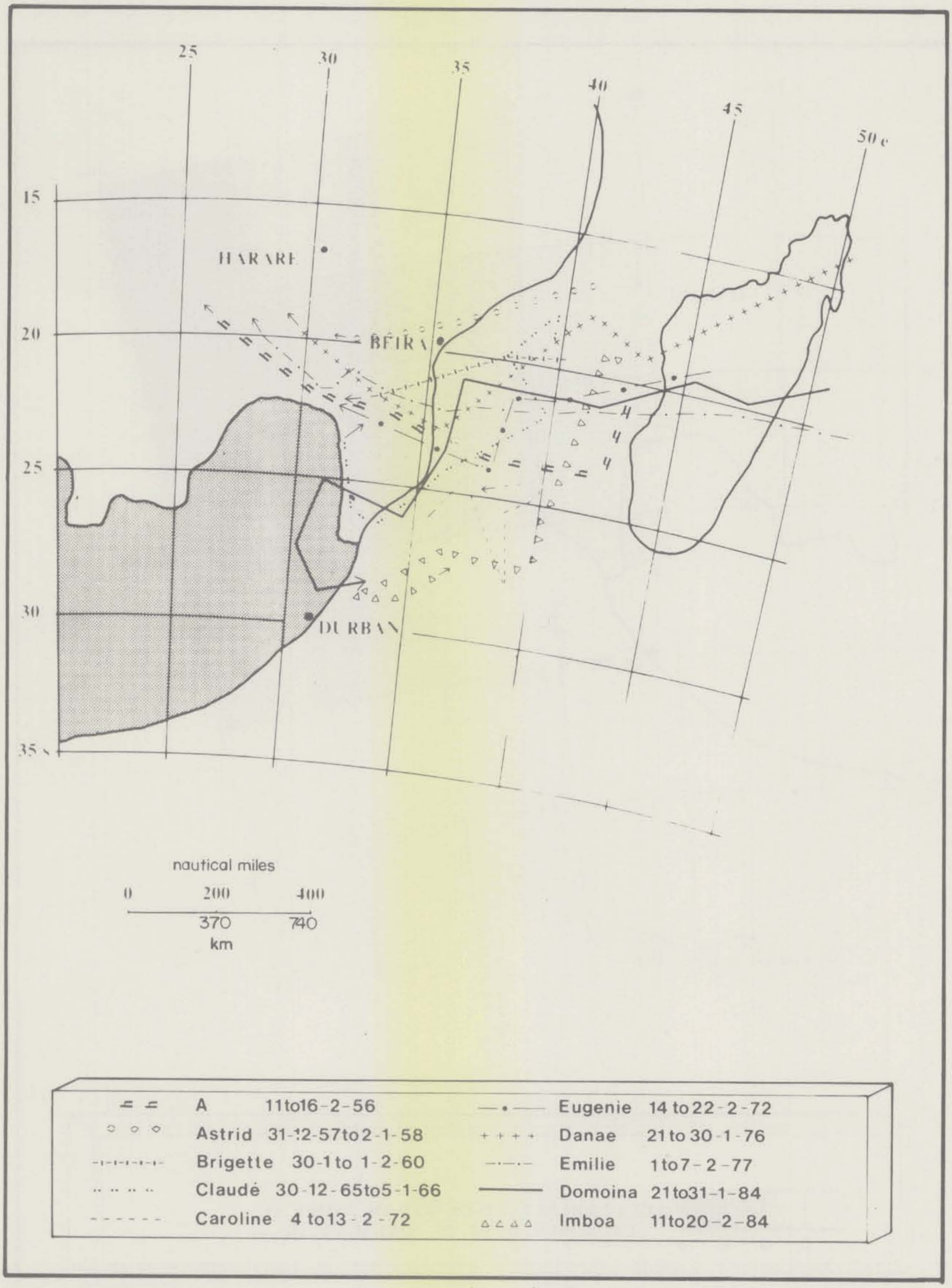
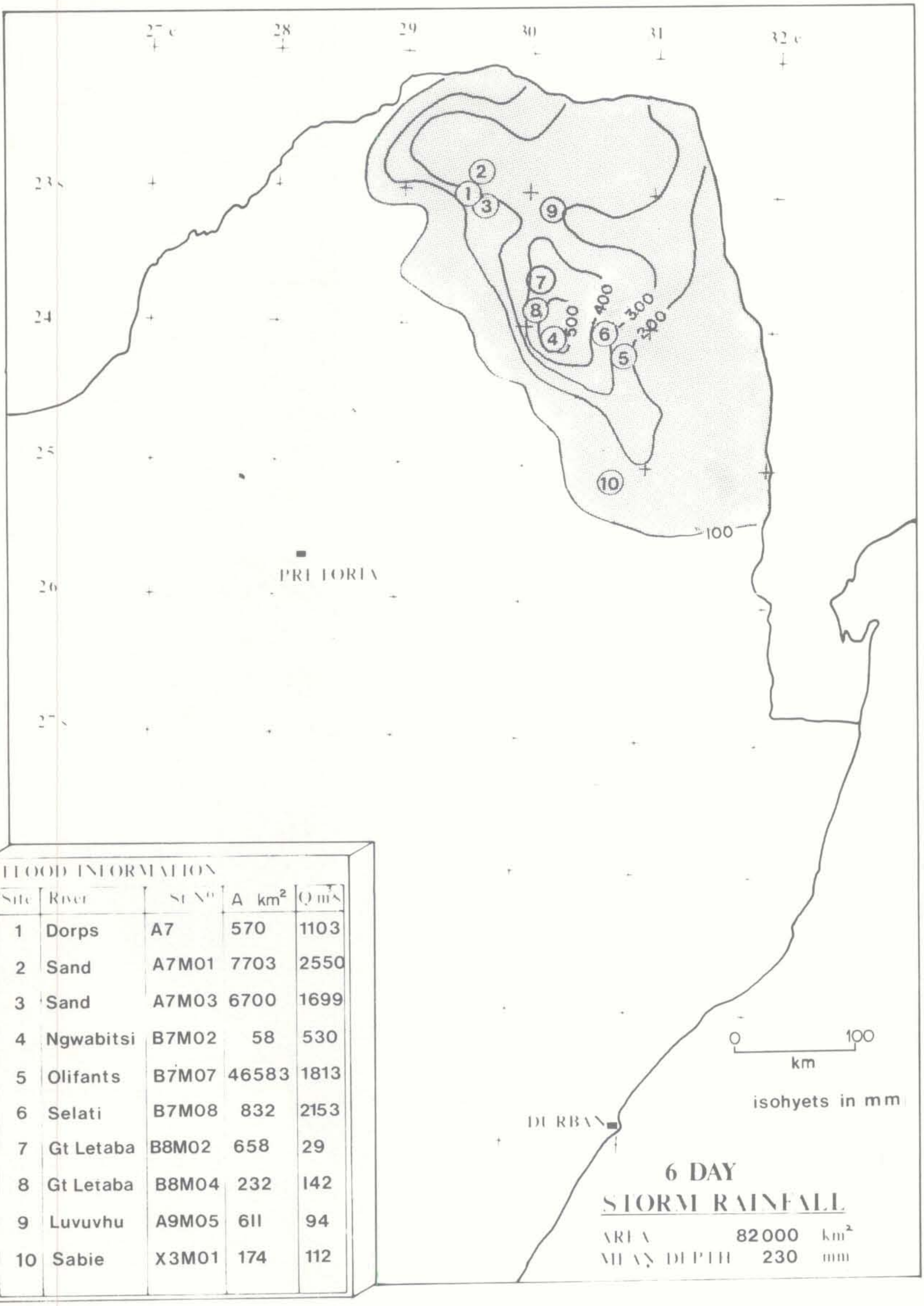


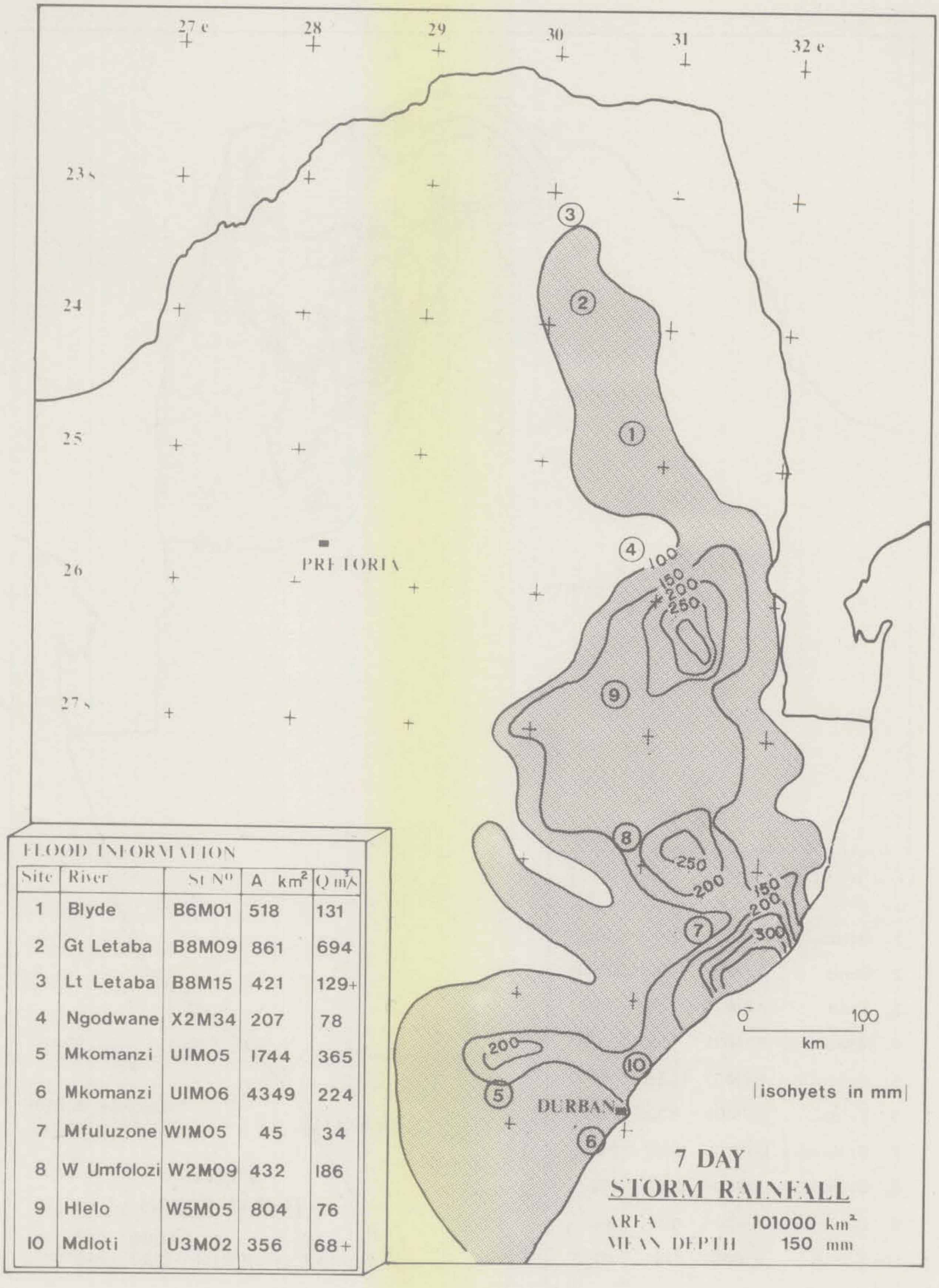
FIG. 3.4 PATHS OF TROPICAL CYCLONES CAUSING SIGNIFICANT RAINFALL OVER SOUTH AFRICA SINCE 1950



FLOOD INFORMATION

Site	River	St No	A km²	Q m³/s
1	Dorps	A7	570	1103
2	Sand	A7M01	7703	2550
3	Sand	A7M03	6700	1699
4	Ngwabitsi	B7M02	58	530
5	Olifants	B7M07	46583	1813
6	Selati	B7M08	832	2153
7	Gt Letaba	B8M02	658	29
8	Gt Letaba	B8M04	232	142
9	Luvuvhu	A9M05	611	94
10	Sabie	X3M01	174	112

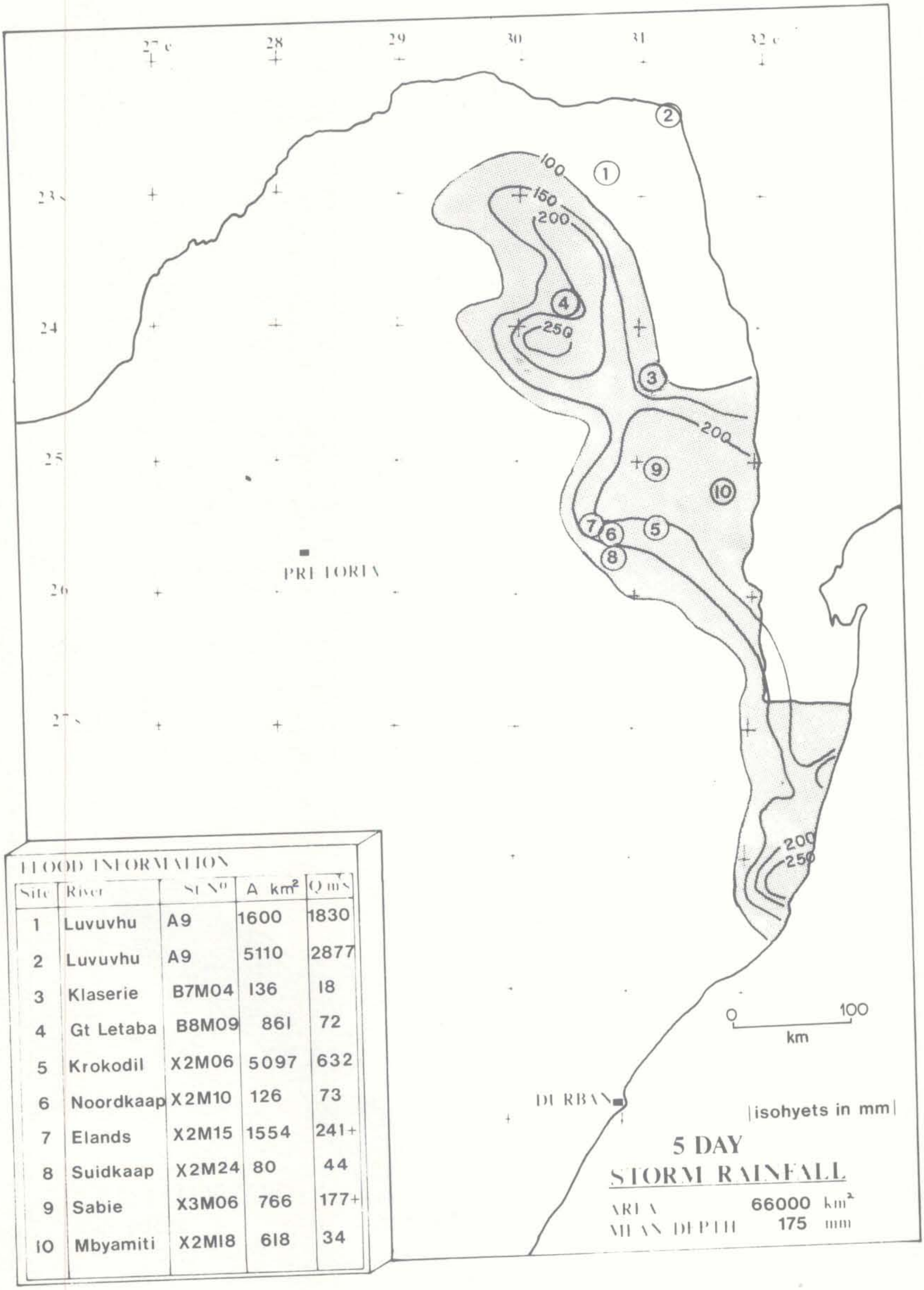
FIG.3.5a ISOHYETAL MAP OF TROPICAL CYCLONE 'ASTRID', 1958



FLOOD INFORMATION

Site	River	St No	A km²	Q m³/s
1	Blyde	B6M01	518	131
2	Gt Letaba	B8M09	861	694
3	Lt Letaba	B8M15	421	129+
4	Ngodwane	X2M34	207	78
5	Mkomanzi	UIM05	1744	365
6	Mkomanzi	UIM06	4349	224
7	Mfuluzone	WIM05	45	34
8	W Umfolozi	W2M09	432	186
9	Hlelo	W5M05	804	76
10	Mdloti	U3M02	356	68+

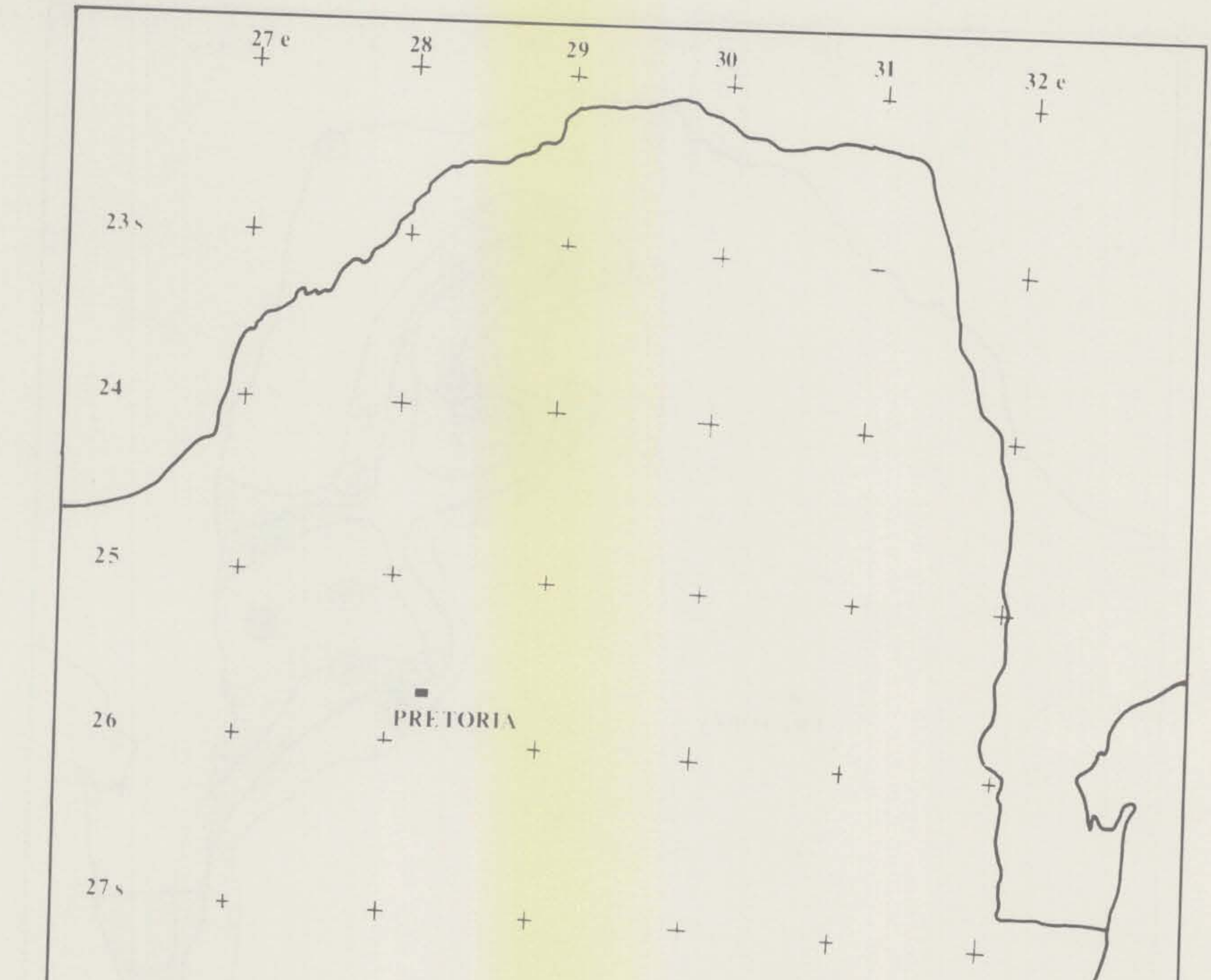
FIG.3.5b ISOHYETAL MAP OF TROPICAL CYCLONE EUGENIE, 1972



FLOOD INFORMATION

Site	River	St Nº	A km^2	Q m^3/s
1	Luvuvhu	A9	1600	1830
2	Luvuvhu	A9	5110	2877
3	Klaserie	B7M04	136	18
4	Gt Letaba	B8M09	861	72
5	Krokodil	X2M06	5097	632
6	Noordkaap	X2M10	126	73
7	Elands	X2M15	1554	241+
8	Suidkaap	X2M24	80	44
9	Sabie	X3M06	766	177+
10	Mbyamiti	X2M18	618	34

FIG.3.5c ISOHYETAL MAP OF TROPICAL CYCLONE 'DANAE', 1976



Site	River	St Nº	A km²	Q m³/s
1	Mhlatuze	W1R01	1273	1290
2	Mfuluzone	W1M05	45	99

FIG.3.5d ISOHYETAL MAP OF TROPICAL CYCLONE IMBOA, 1984

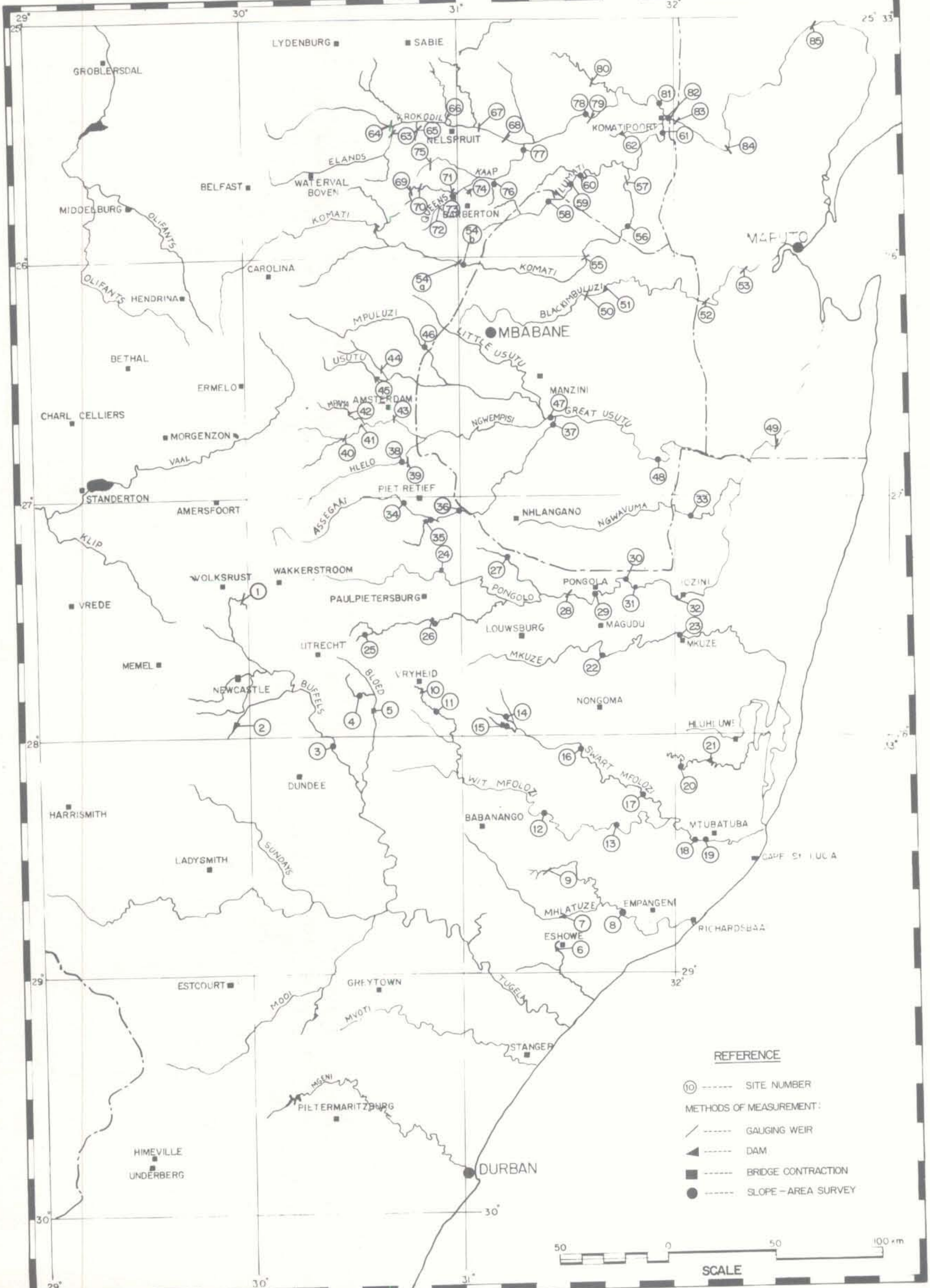


FIG. 4.1 FLOOD PEAK MEASUREMENT SITES

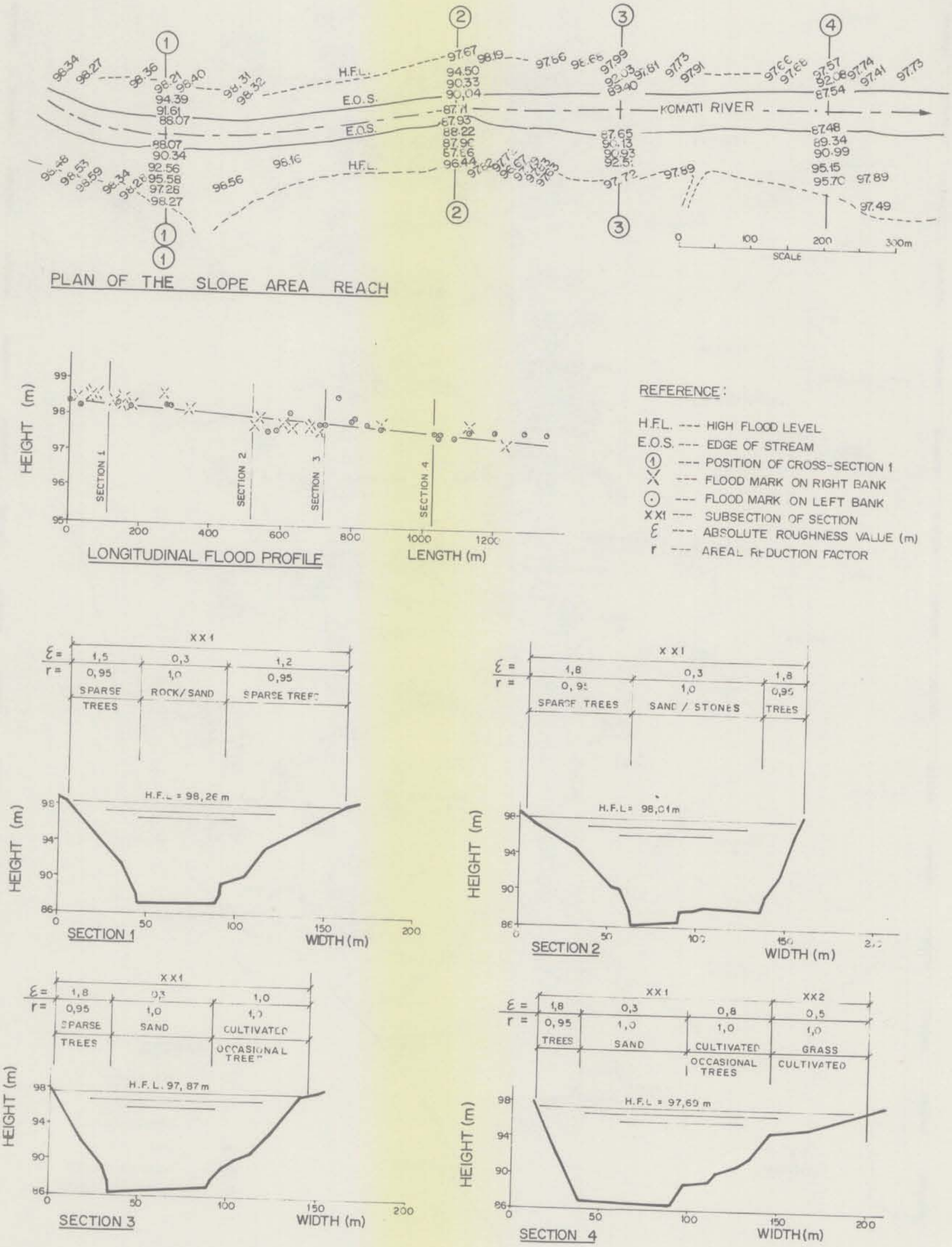


FIG. 4·2 SLOPE AREA SURVEY AT SITE 56 : PLAN AND SECTIONS

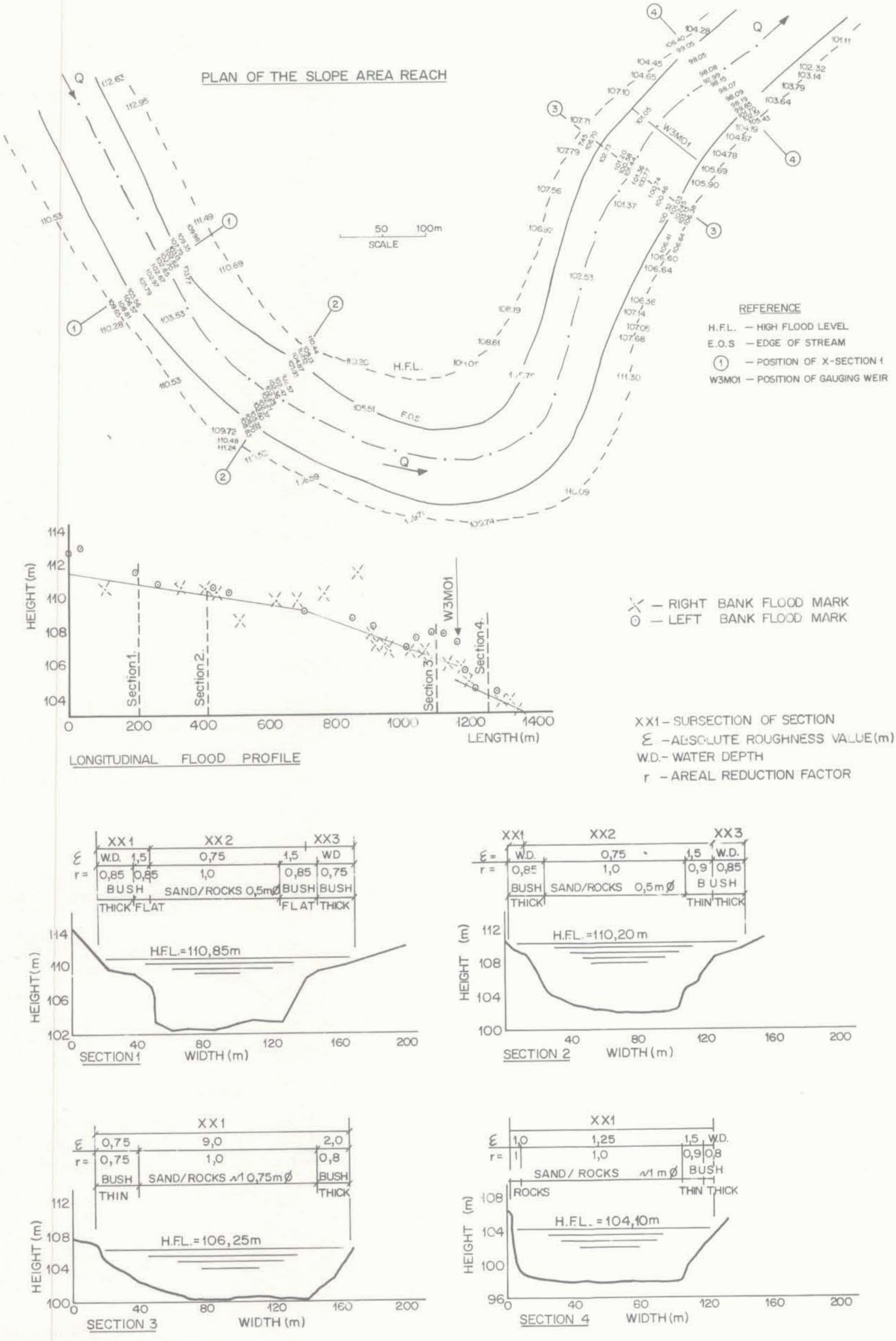


FIG. 4.3 SLOPE AREA SURVEY AT SITE 22 : PLAN AND SECTIONS

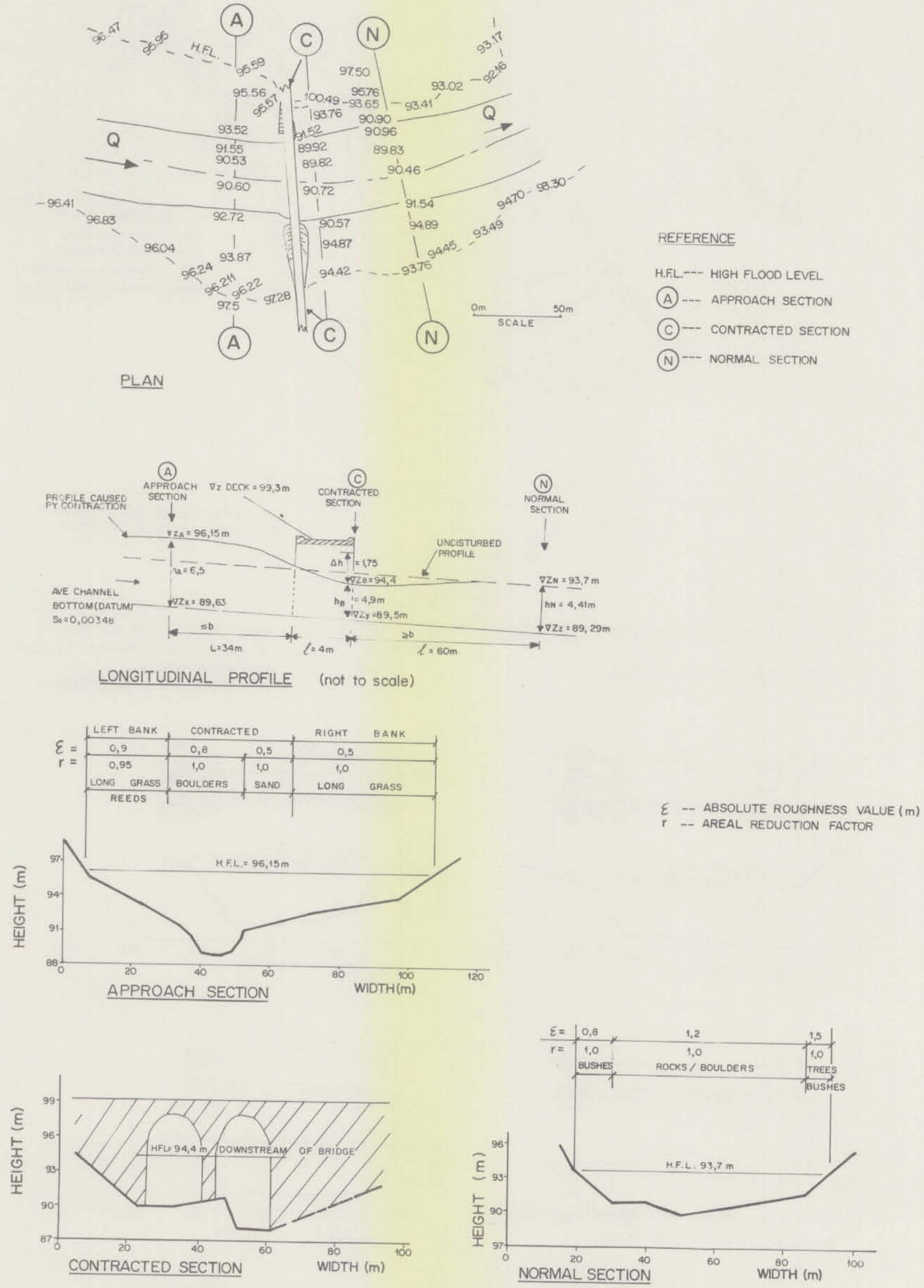


FIG. 4.4 BRIDGE SURVEY AT SITE 26: PLAN AND SECTIONS

$$Y_C = \frac{\Delta X_{BA} + Y_A \tan \phi_{AC} - Y_B \tan \phi_{BC}}{\tan \phi_{AC} - \tan \phi_{BC}}$$

$$X_C = X_A + \Delta Y_{AC} \tan \phi_{AC}$$

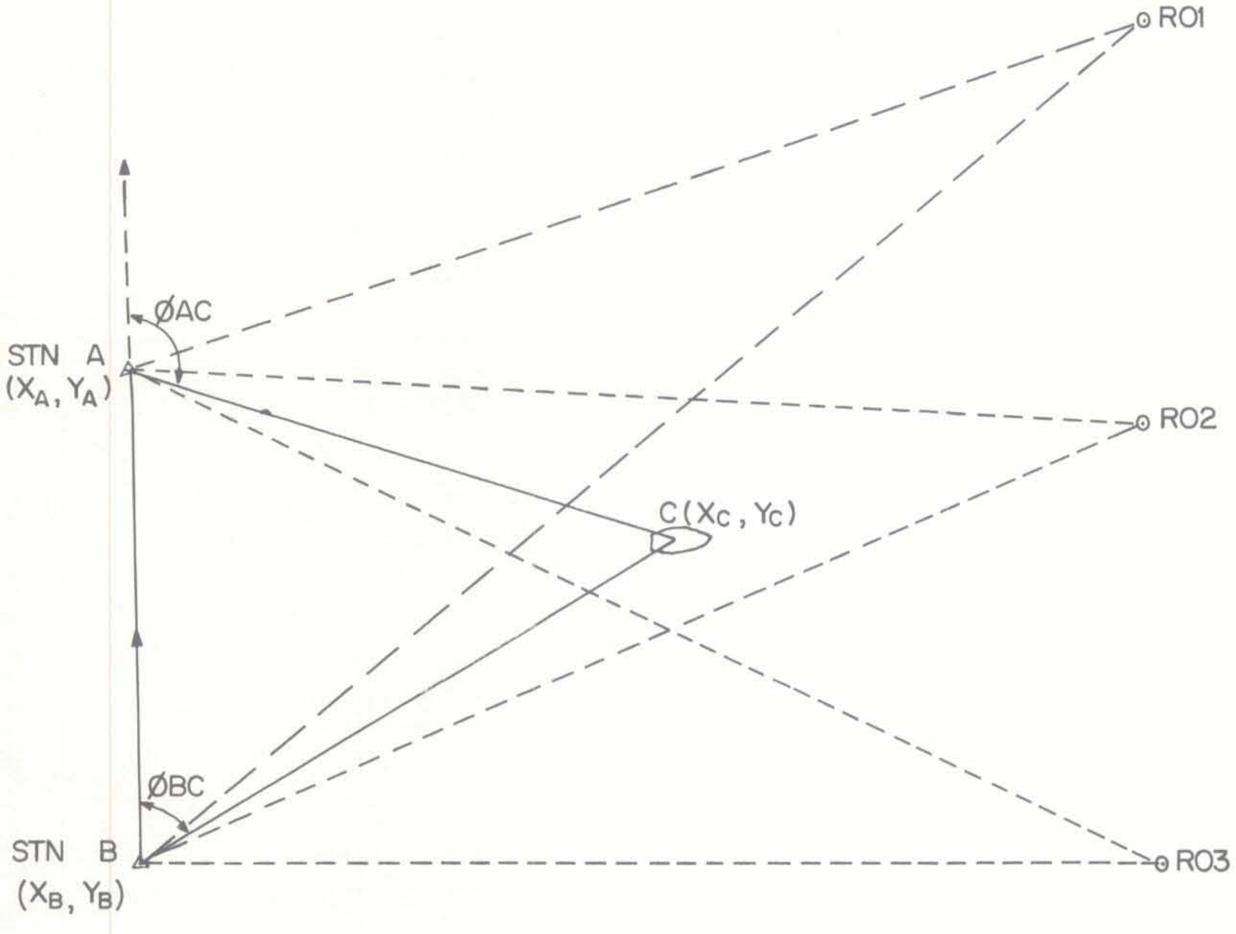


FIG. 4.5 PONGOLAPOORT DAM : PRINCIPLE OF SURVEY

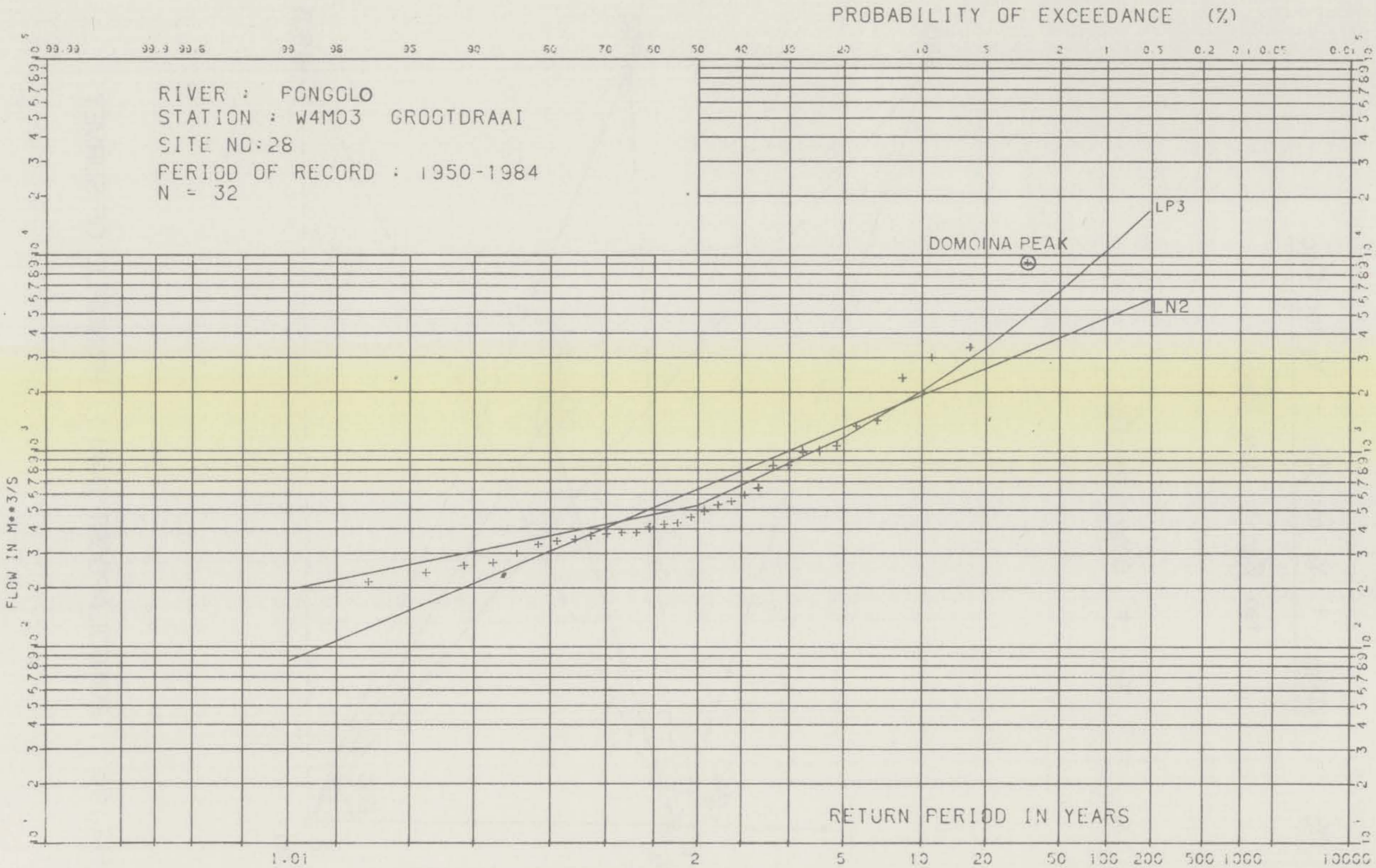


FIG.5.1 FLOOD PEAK FREQUENCY DISTRIBUTIONS AT SITE 28

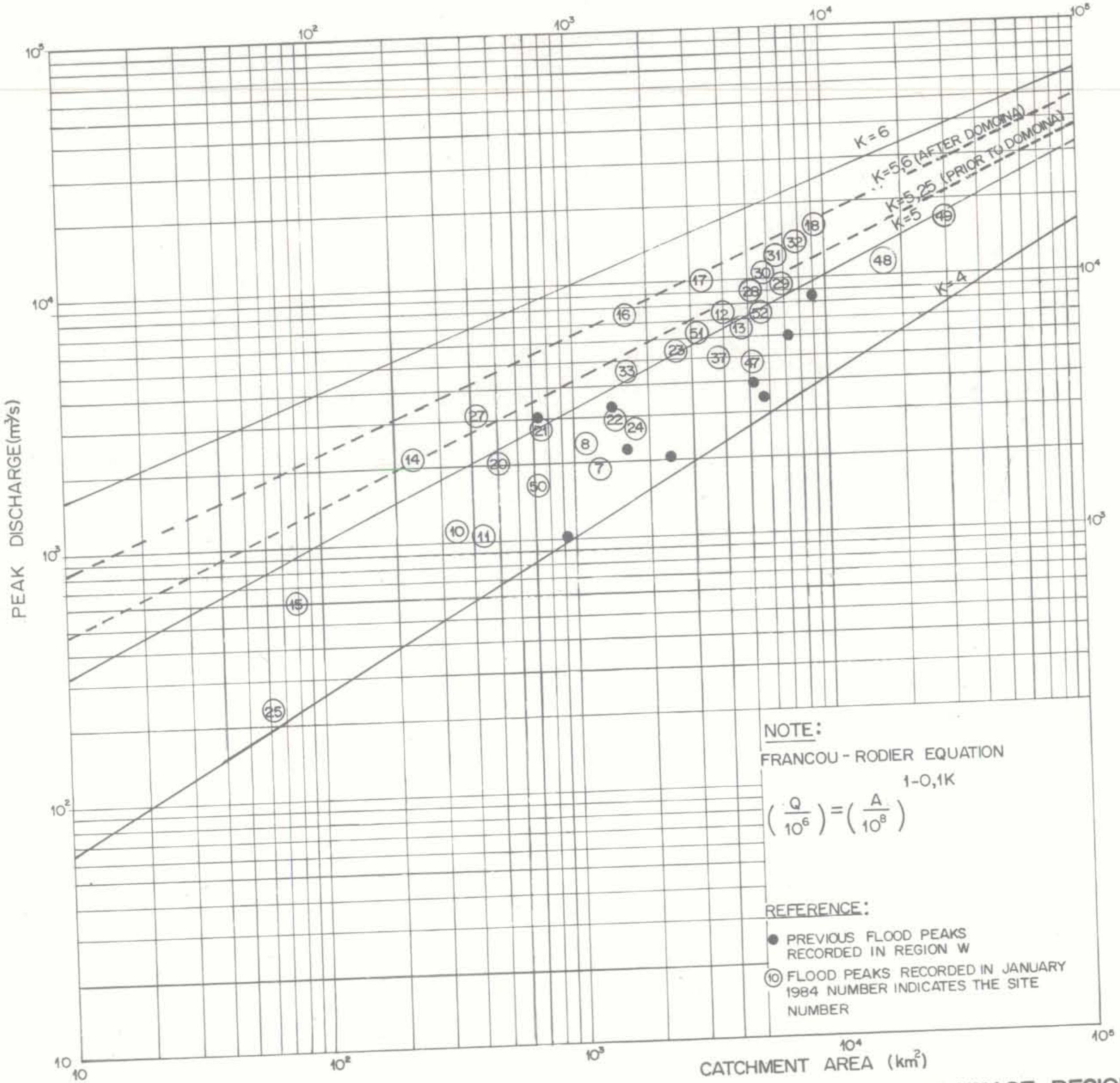


FIG. 5.2 MAXIMUM PEAK DISCHARGES WITH FRANCOU-RODIER K ≥ 4 IN DRAINAGE REGION W

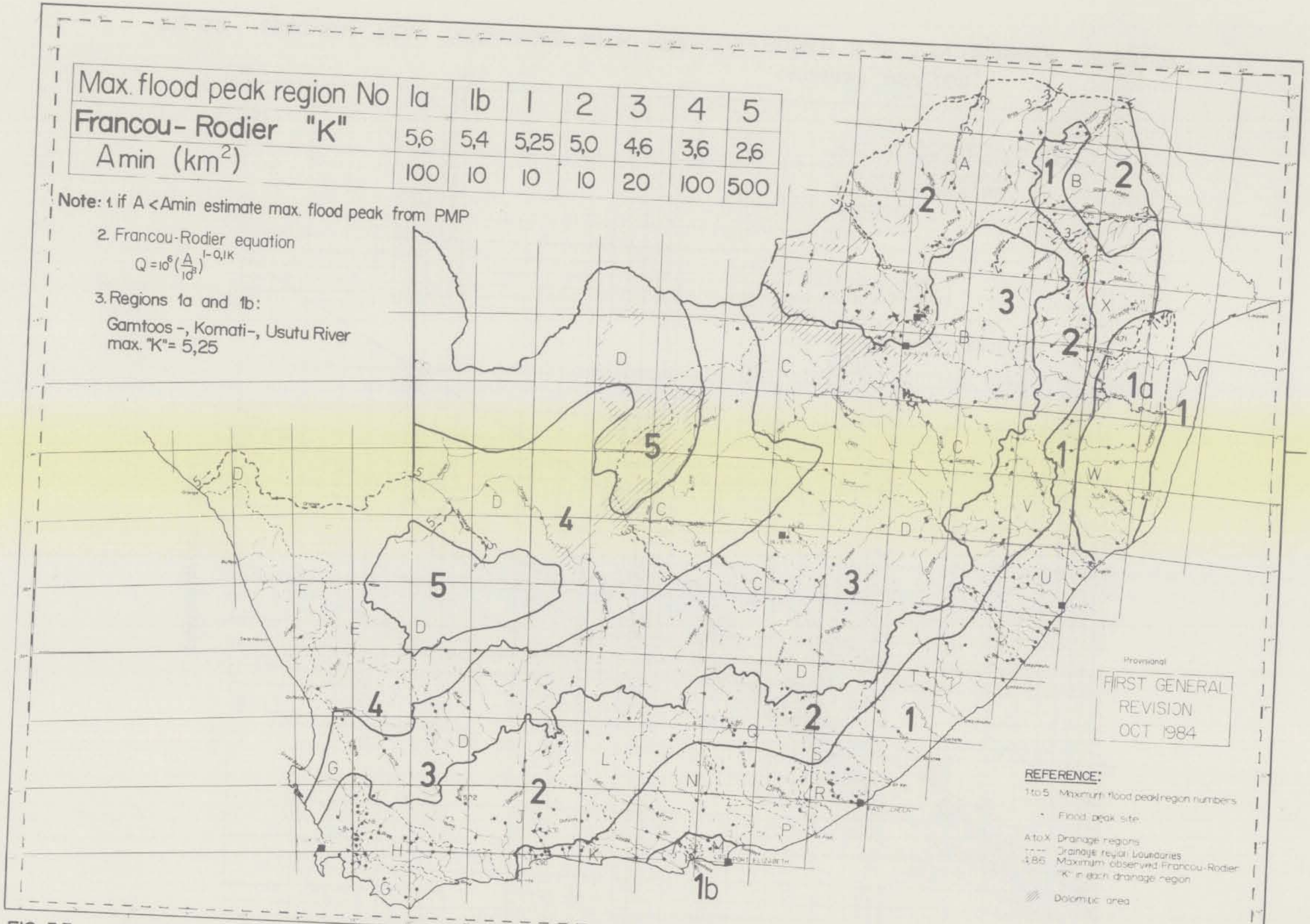


FIG. 5.3 REVISED MAXIMUM PEAK DISCHARGE REGION BOUNDARIES AND FRANCOU – RODIER "K" VALUES

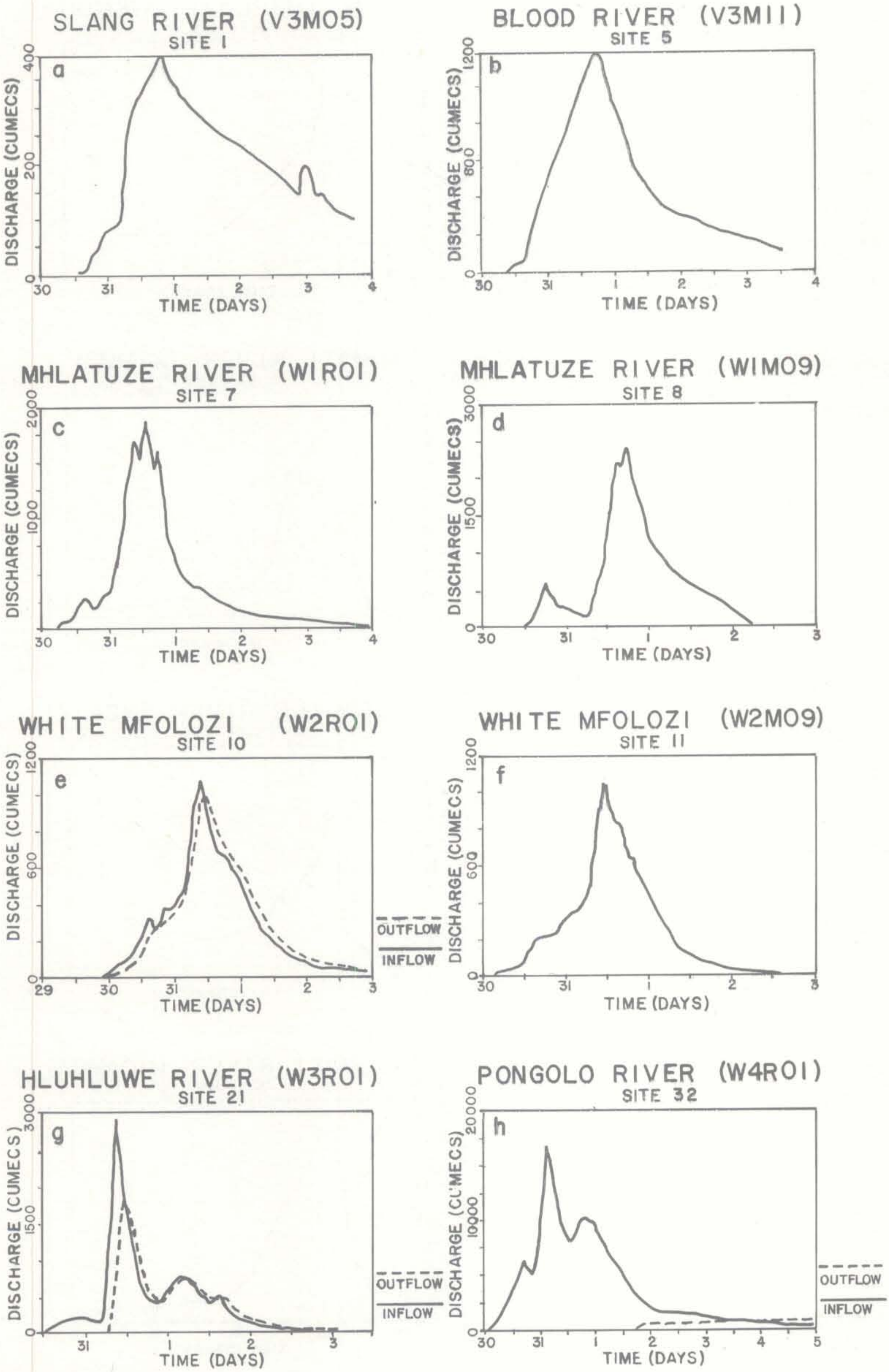


FIG. 6.1 (a - h) FLOOD HYDROGRAPHS

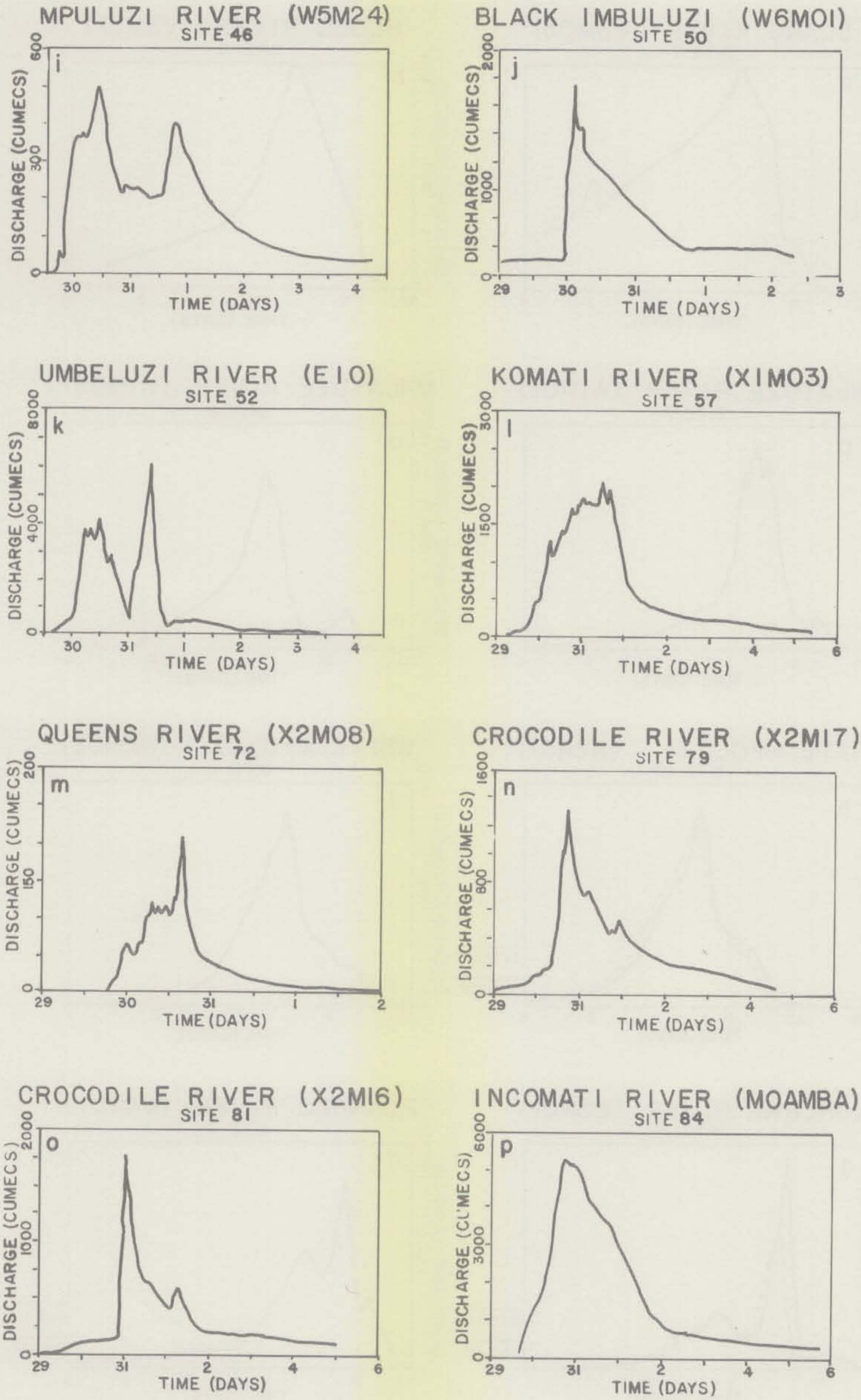


FIG. 6.1(i-p) FLOOD HYDROGRAPHS

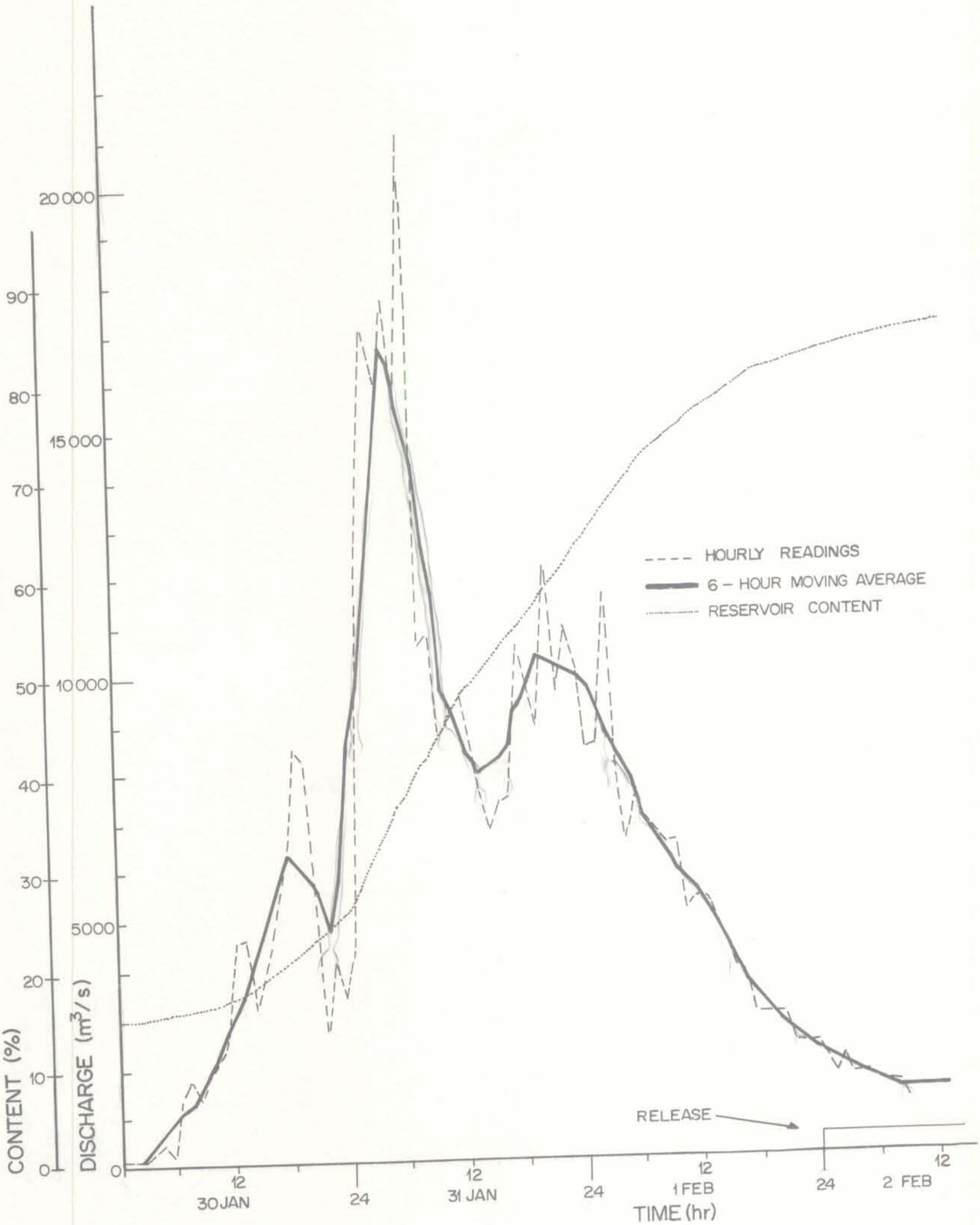


FIG. 6.2 PONGOLAPOORT DAM : INFLOW HYDROGRAPH (SITE 32)

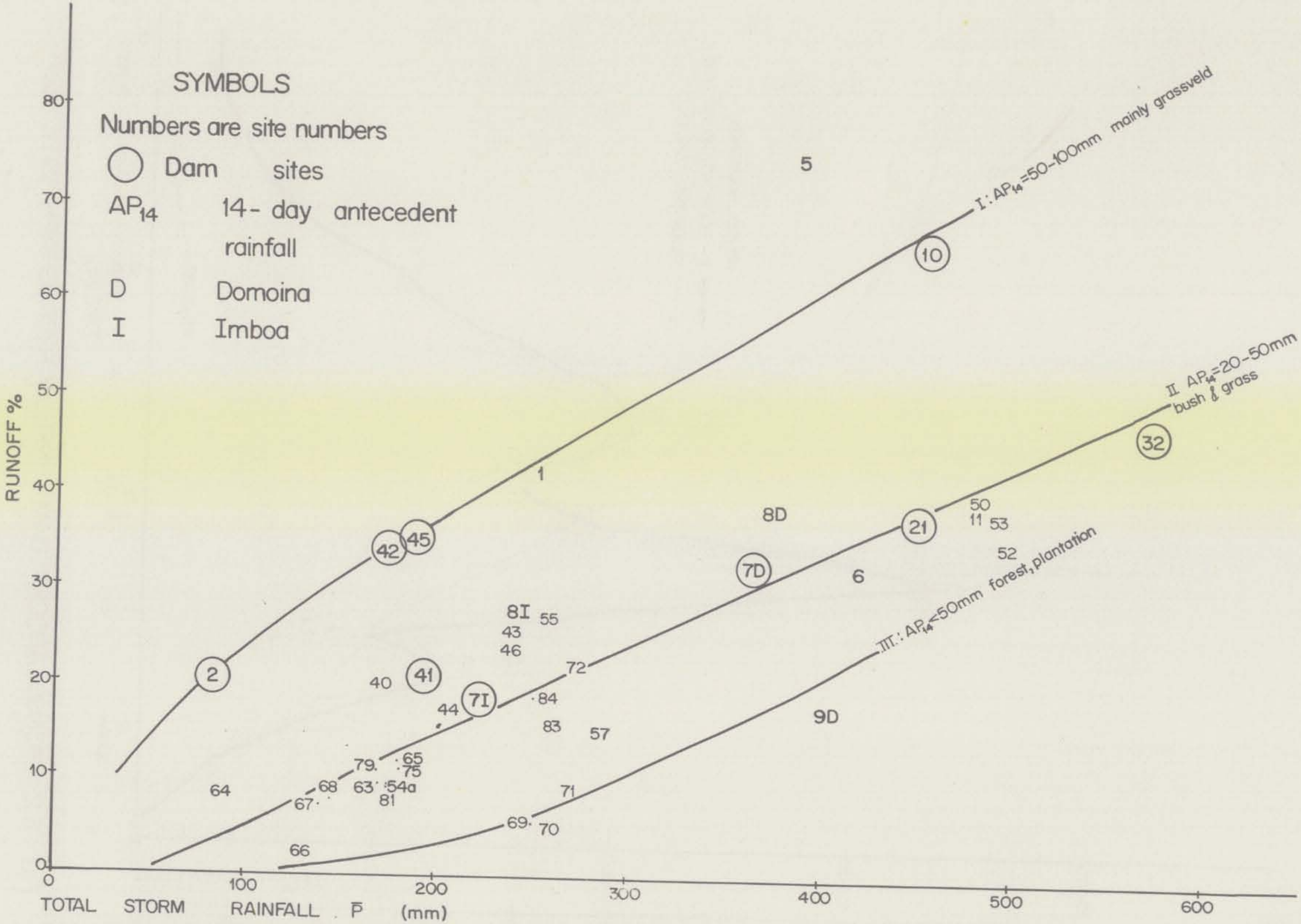
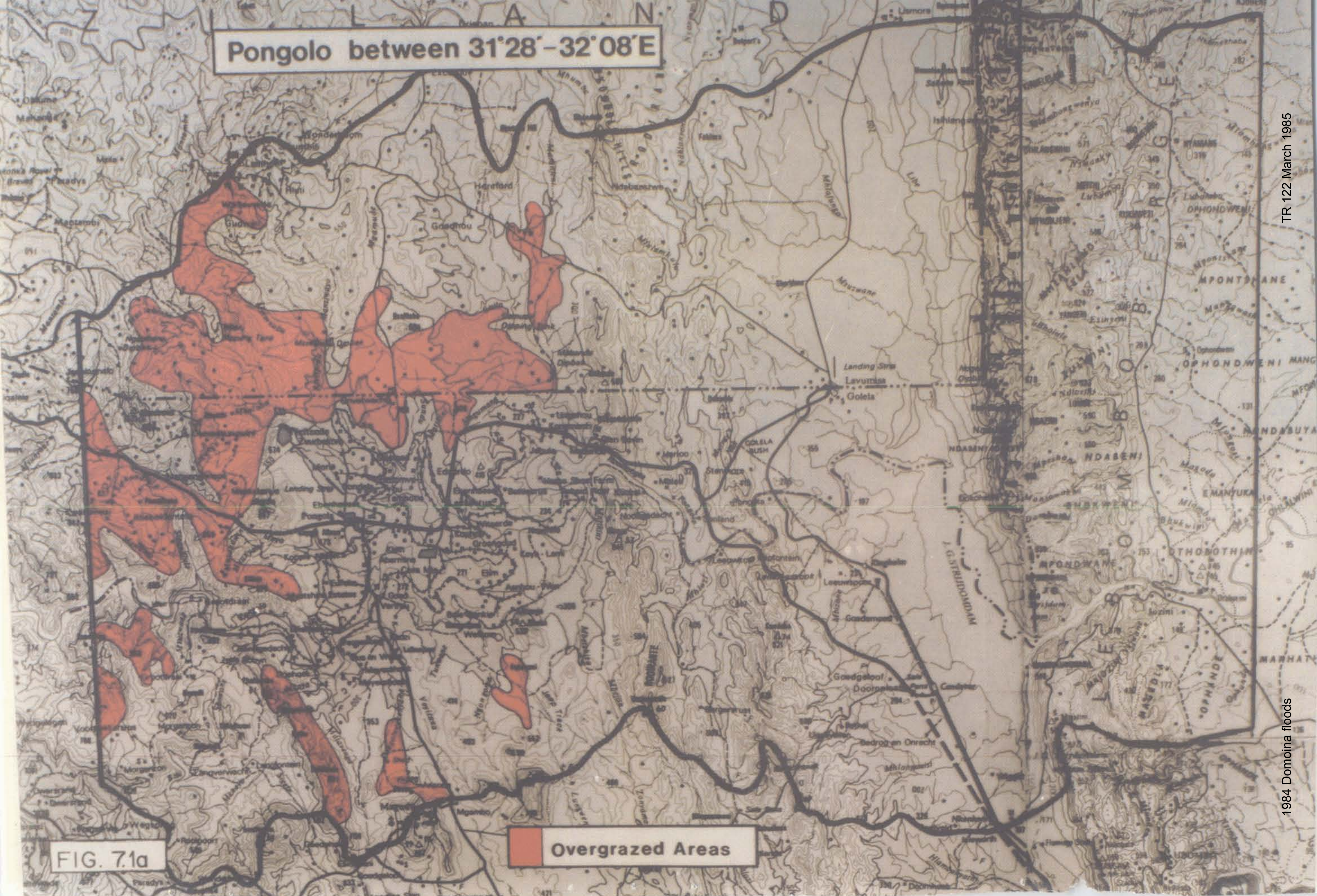


FIG. 6.3 RUNOFF % VERSUS STORM RAINFALL


Pongolo between 31°28′–32°08′E
Overgrazed Areas
Lavumisa
Golela
Landing Strip
J.G. STRIJDOMDAM
MPONTSHANE
OPHONDWENI
NDABENI
MPONDWANE
OTHOBOTHINI
TR 122 March 1985
1984 Domoina floods
FIG. 7.1a

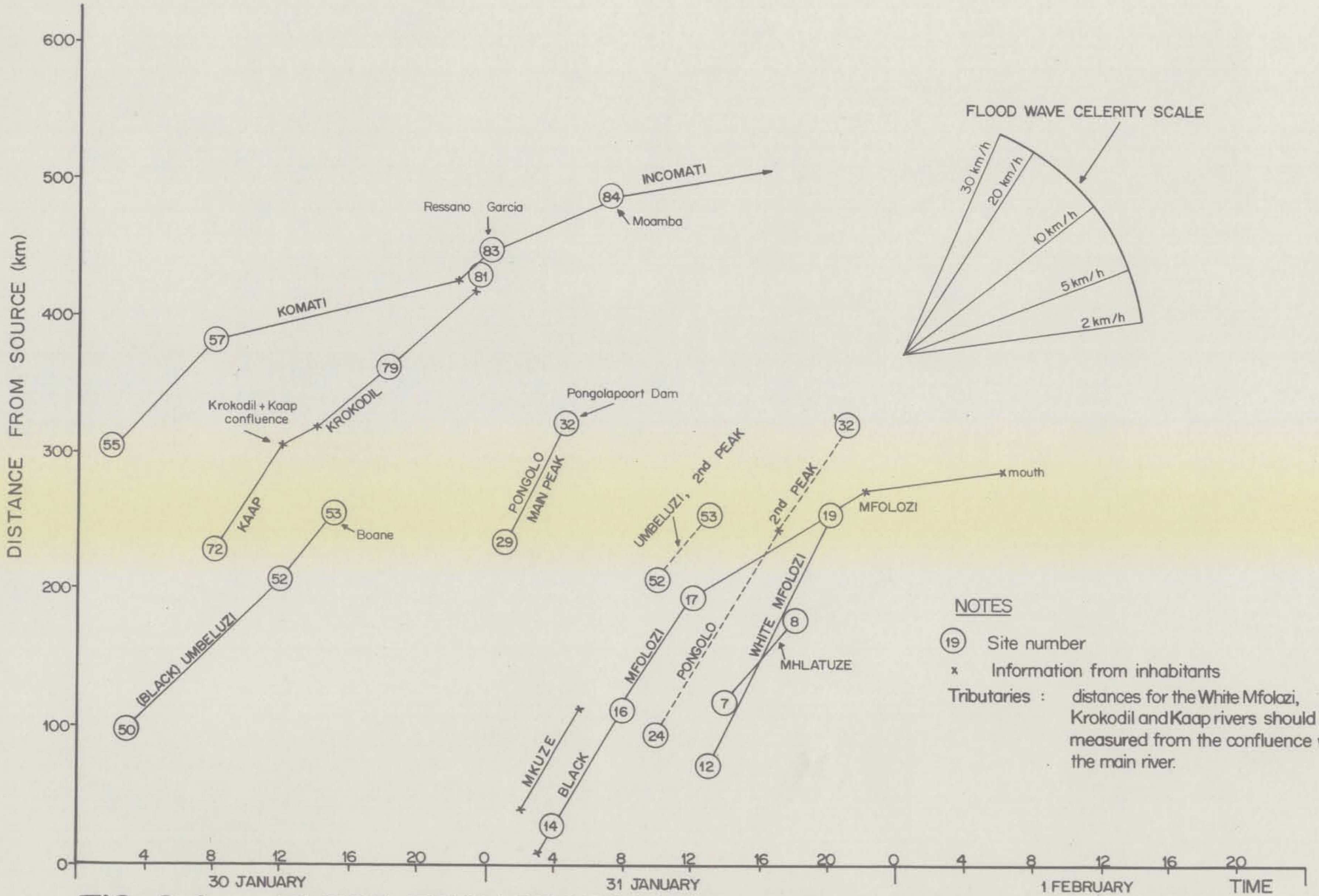


FIG. 6.4 FLOOD PEAK PROPAGATION TIME vs DISTANCE DIAGRAMS

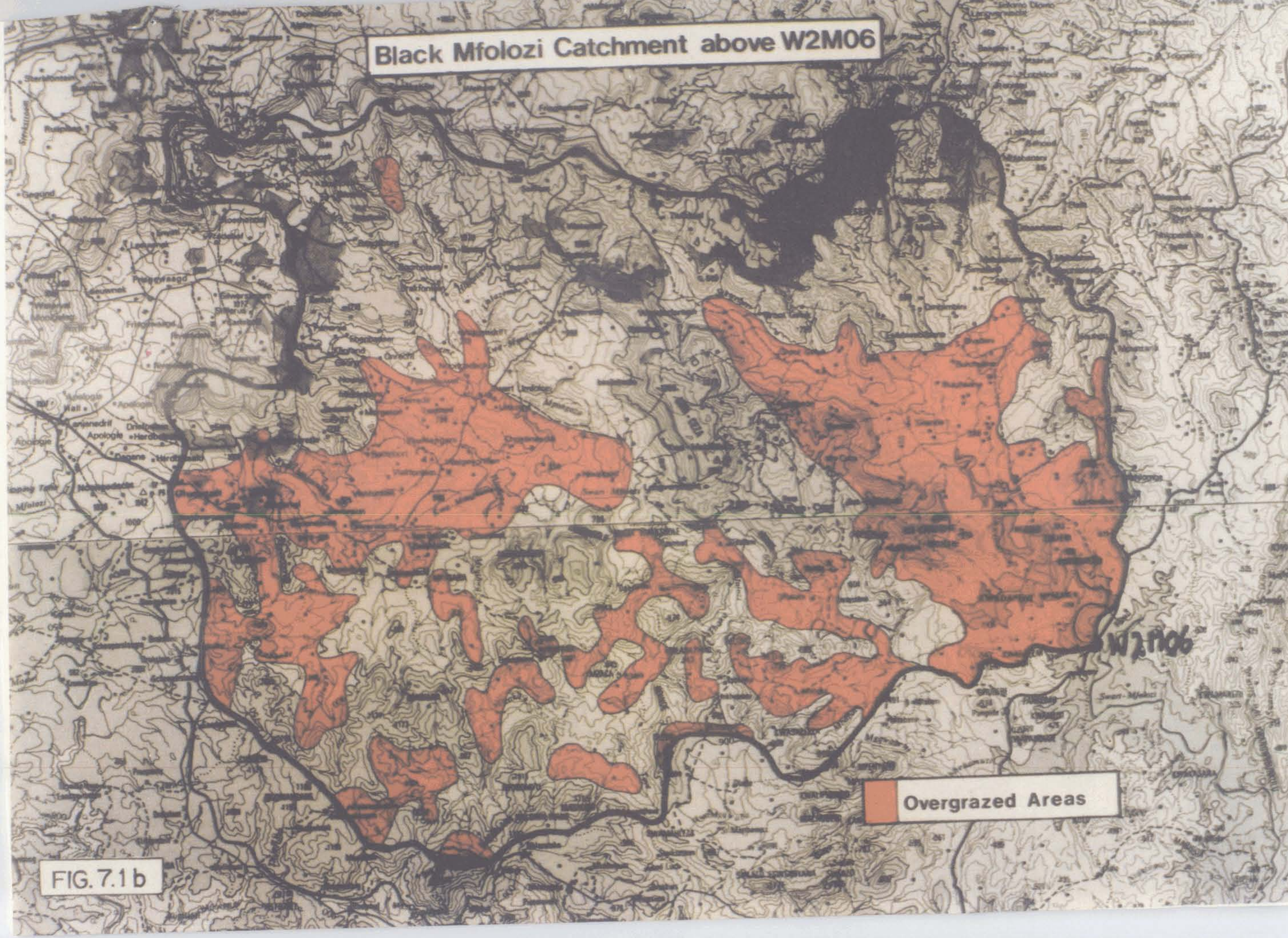

Black Mfolozi Catchment above W2M06
Overgrazed Areas
W2M06

FIG. 7.1 b

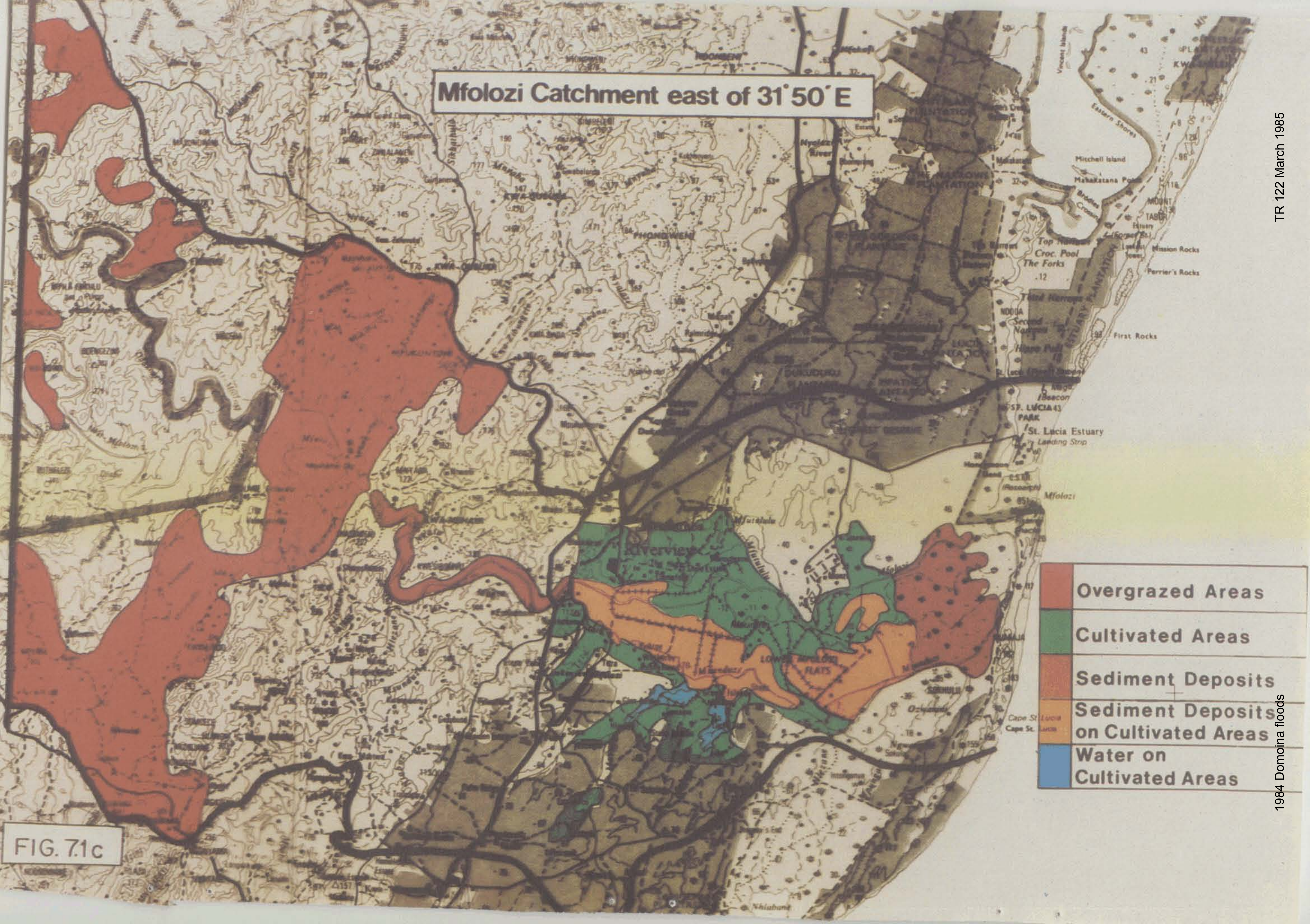


FIG. 7.1c

TR 122 March 1985

1984 Domoina floods

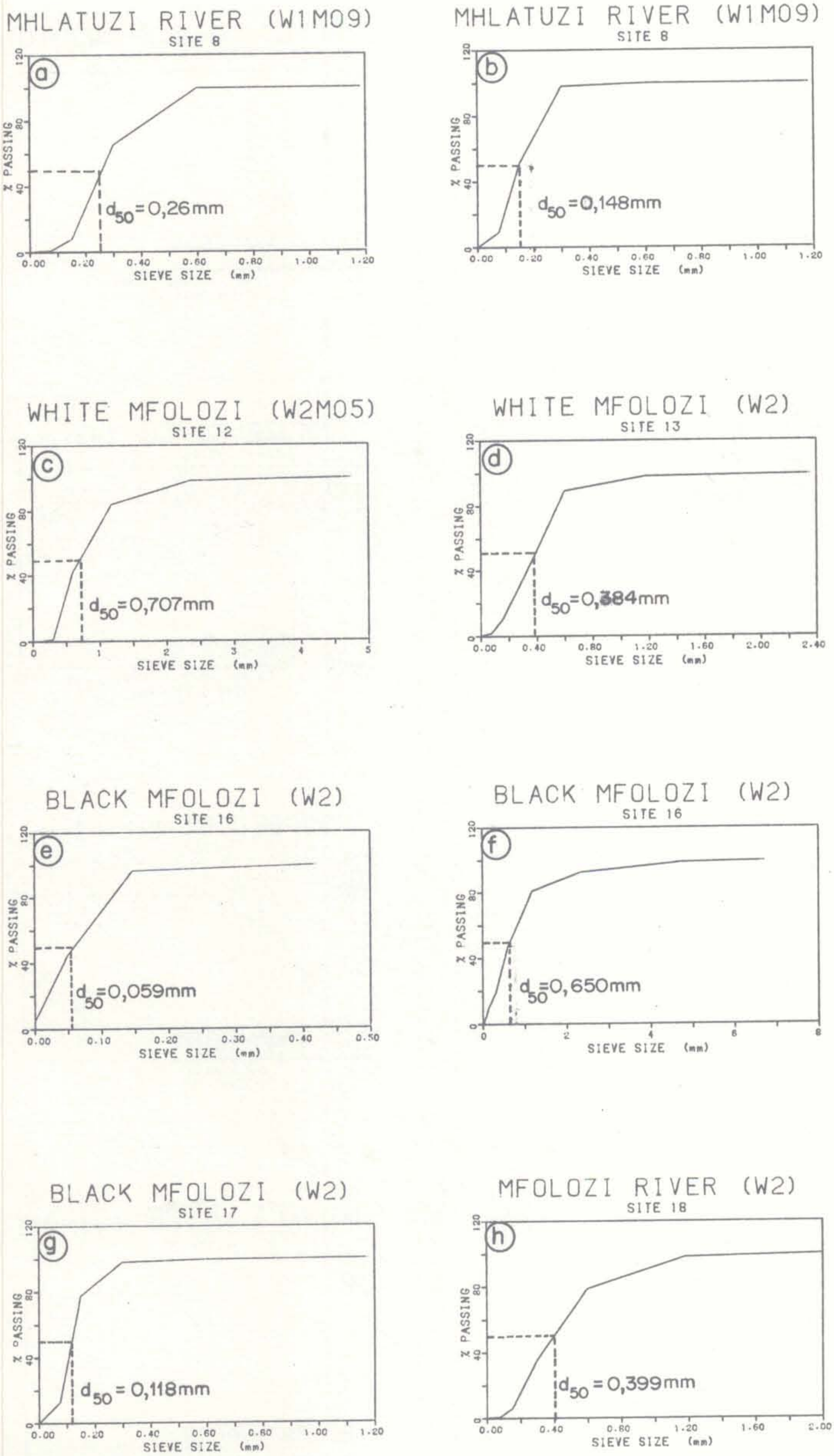


FIG. 7.2 (a–h) SEDIMENT GRADING CURVES

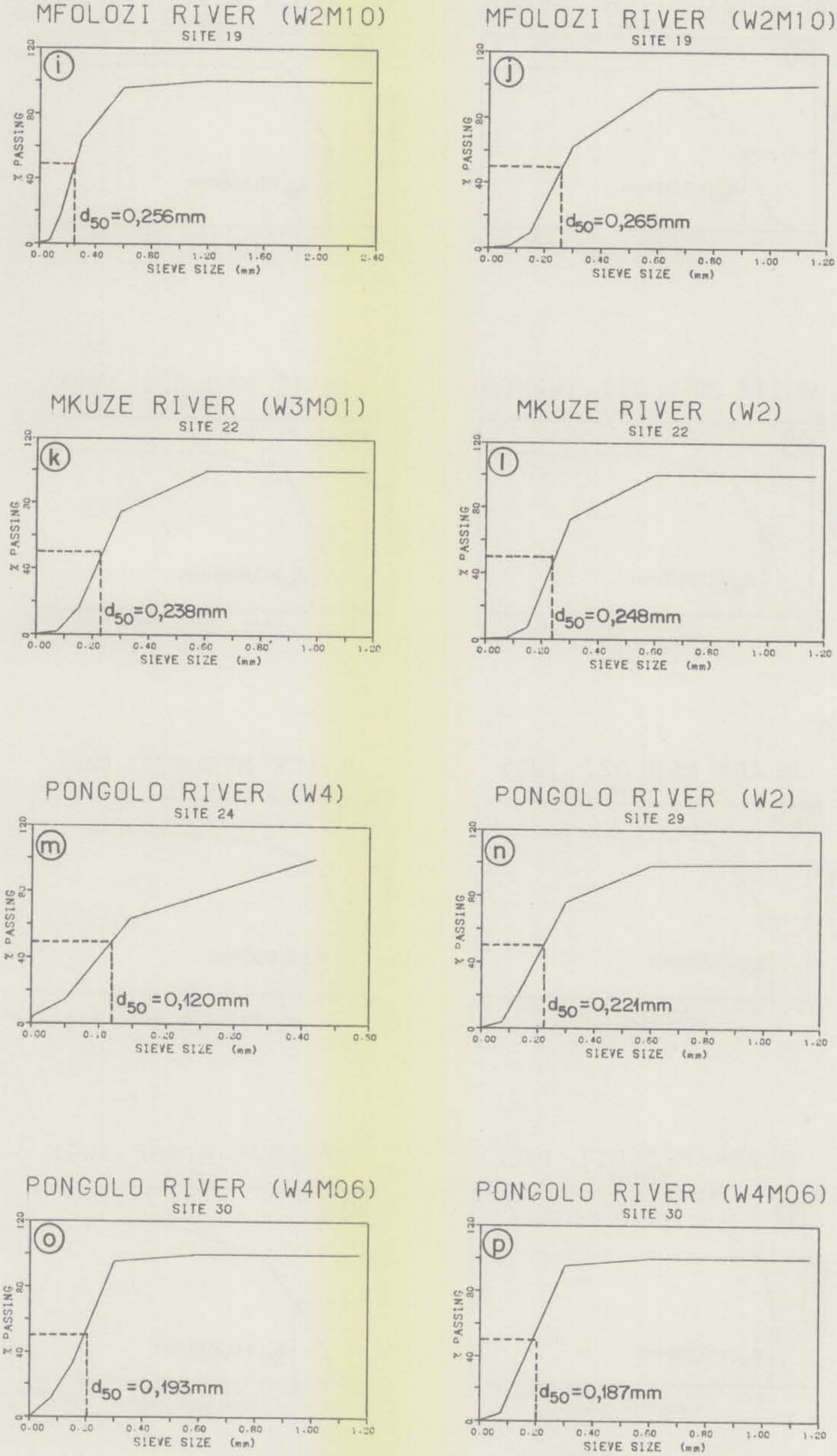


FIG. 7.2(i–p) SEDIMENT GRADING CURVES

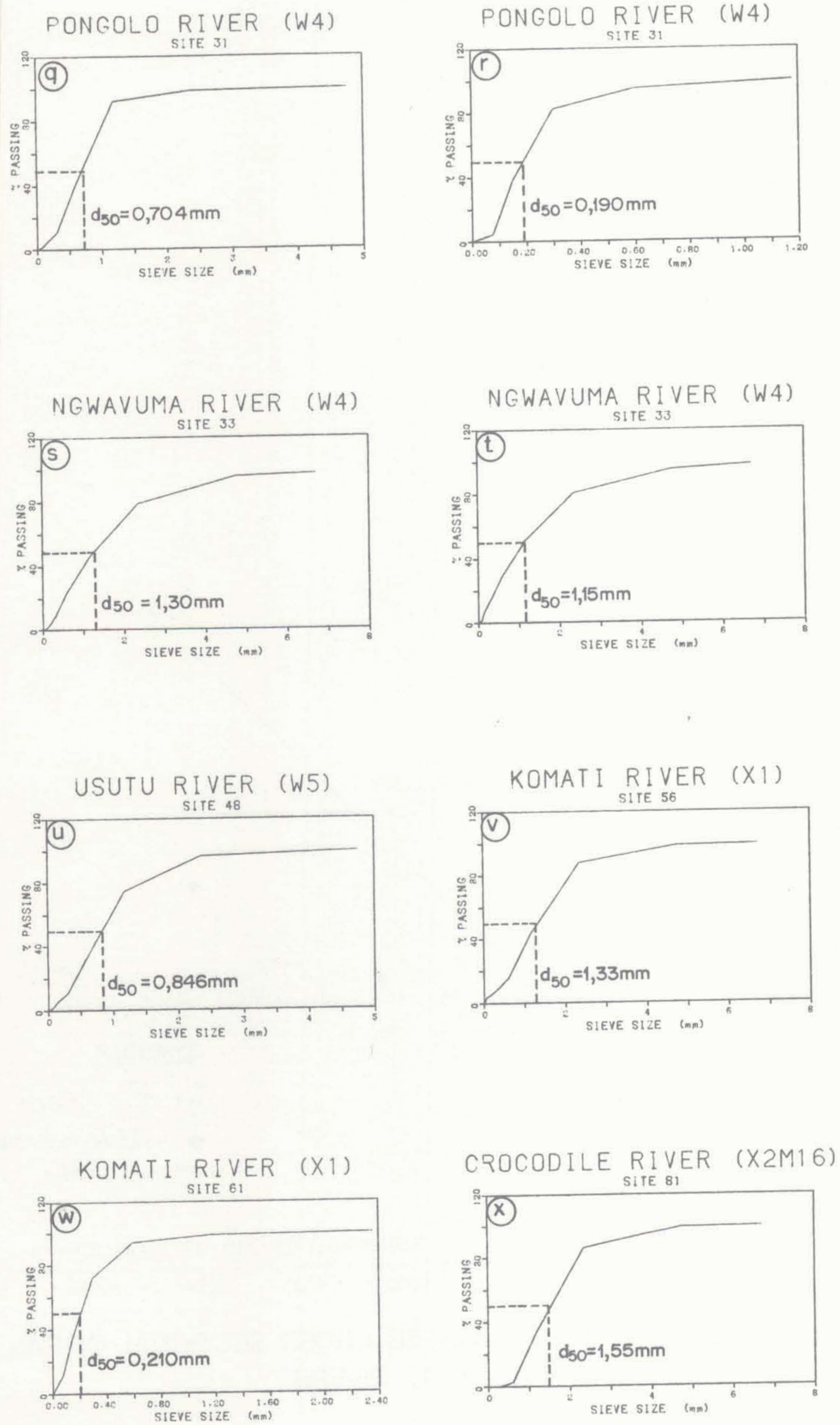


FIG. 7.2 (q – x) SEDIMENT GRADING CURVES

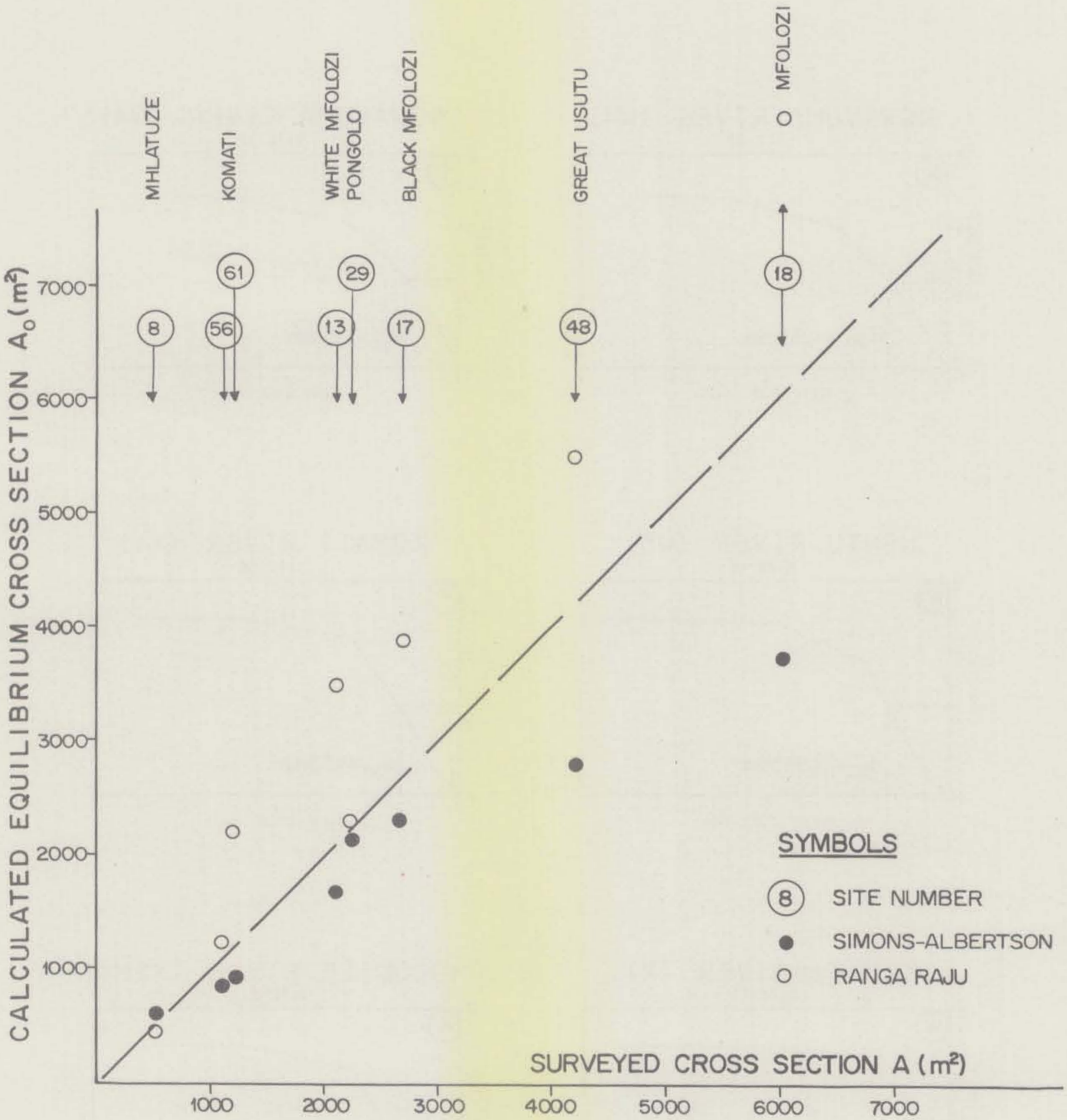


FIG. 7.3 SURVEYED vs CALCULATED CROSS SECTIONAL AREAS IN ALLUVIAL RIVERS

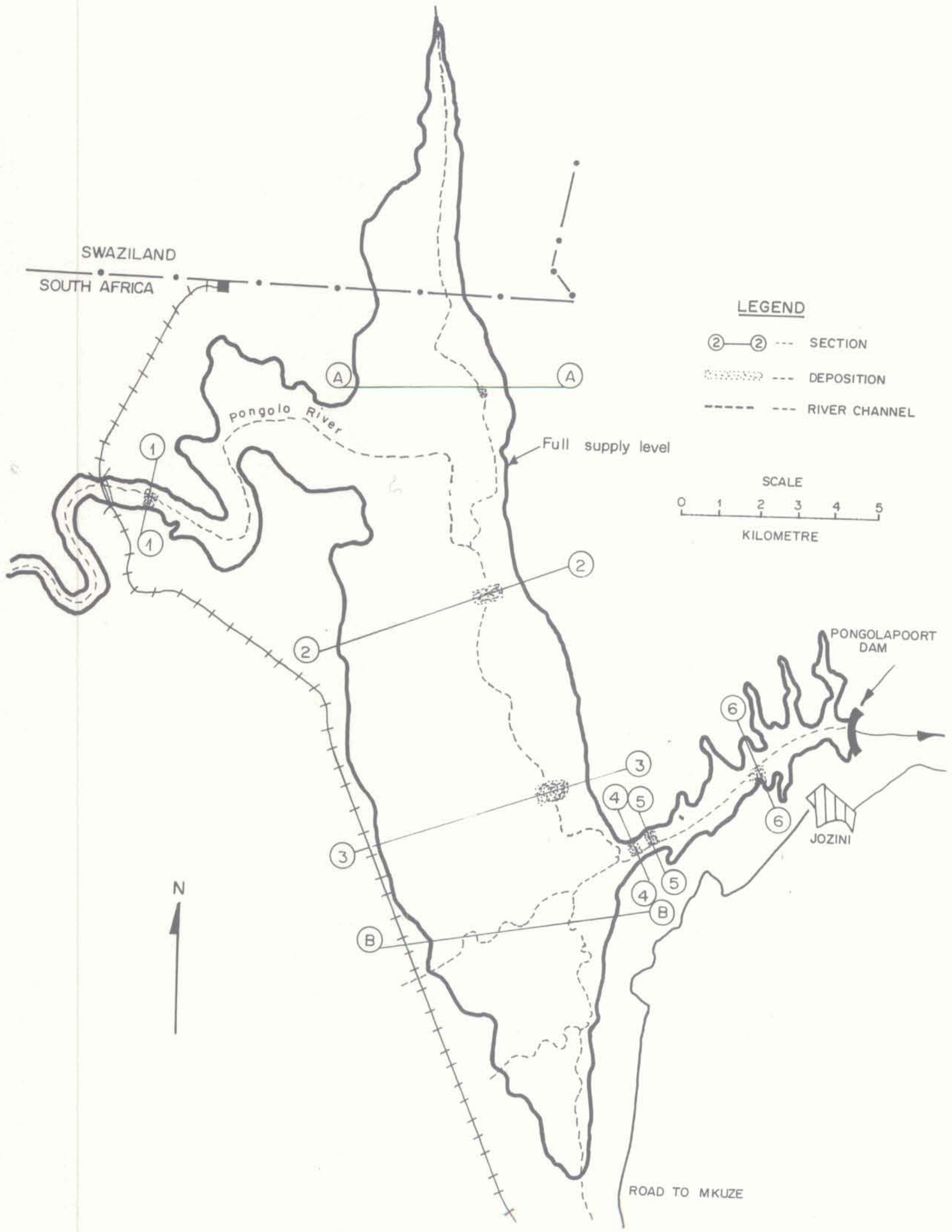


FIG. 7.4 a PONGOLAPOORT DAM : PLAN

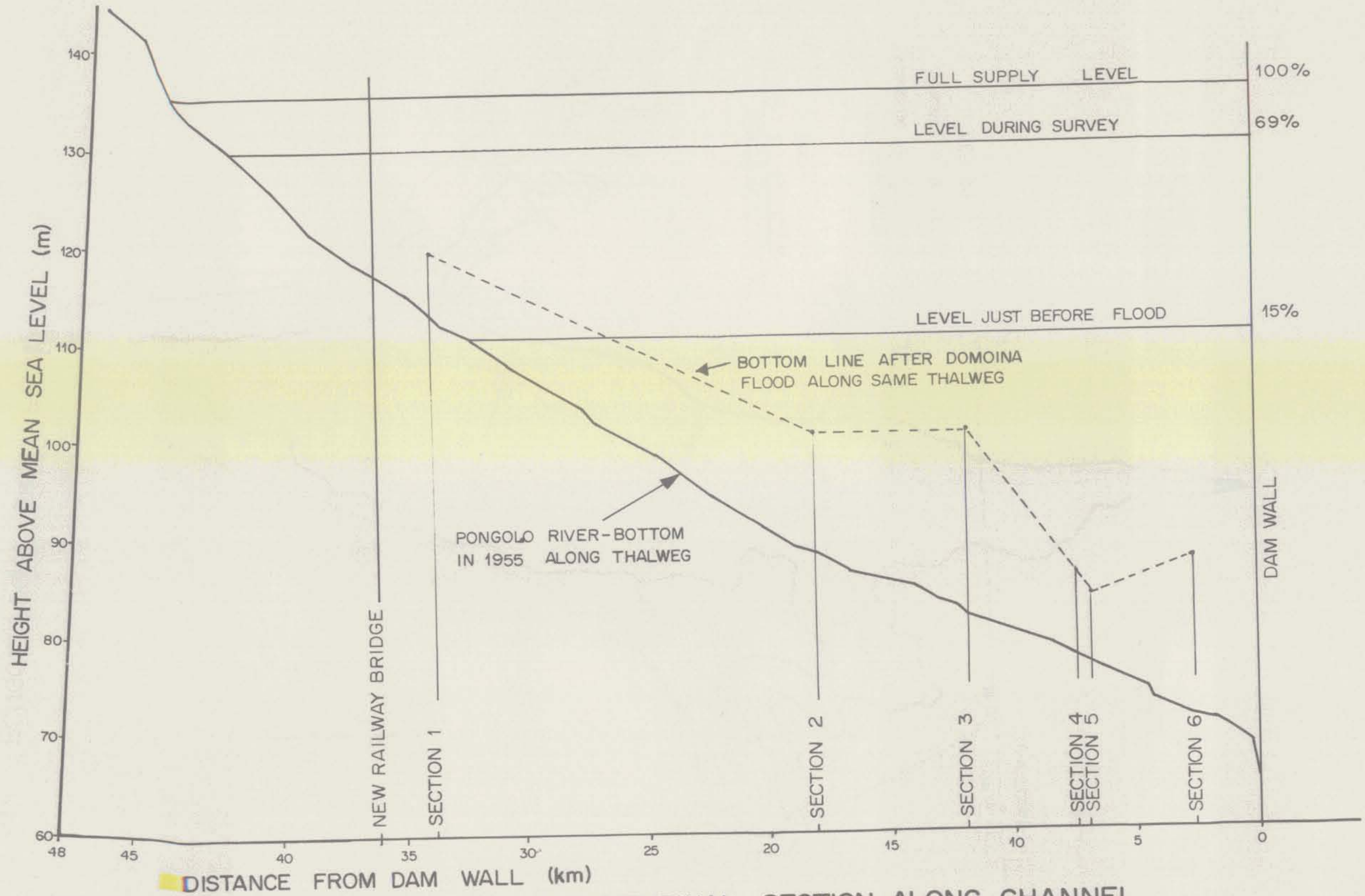


FIG. 7.4 b PONGOLAPOORT DAM: LONGITUDINAL SECTION ALONG CHANNEL

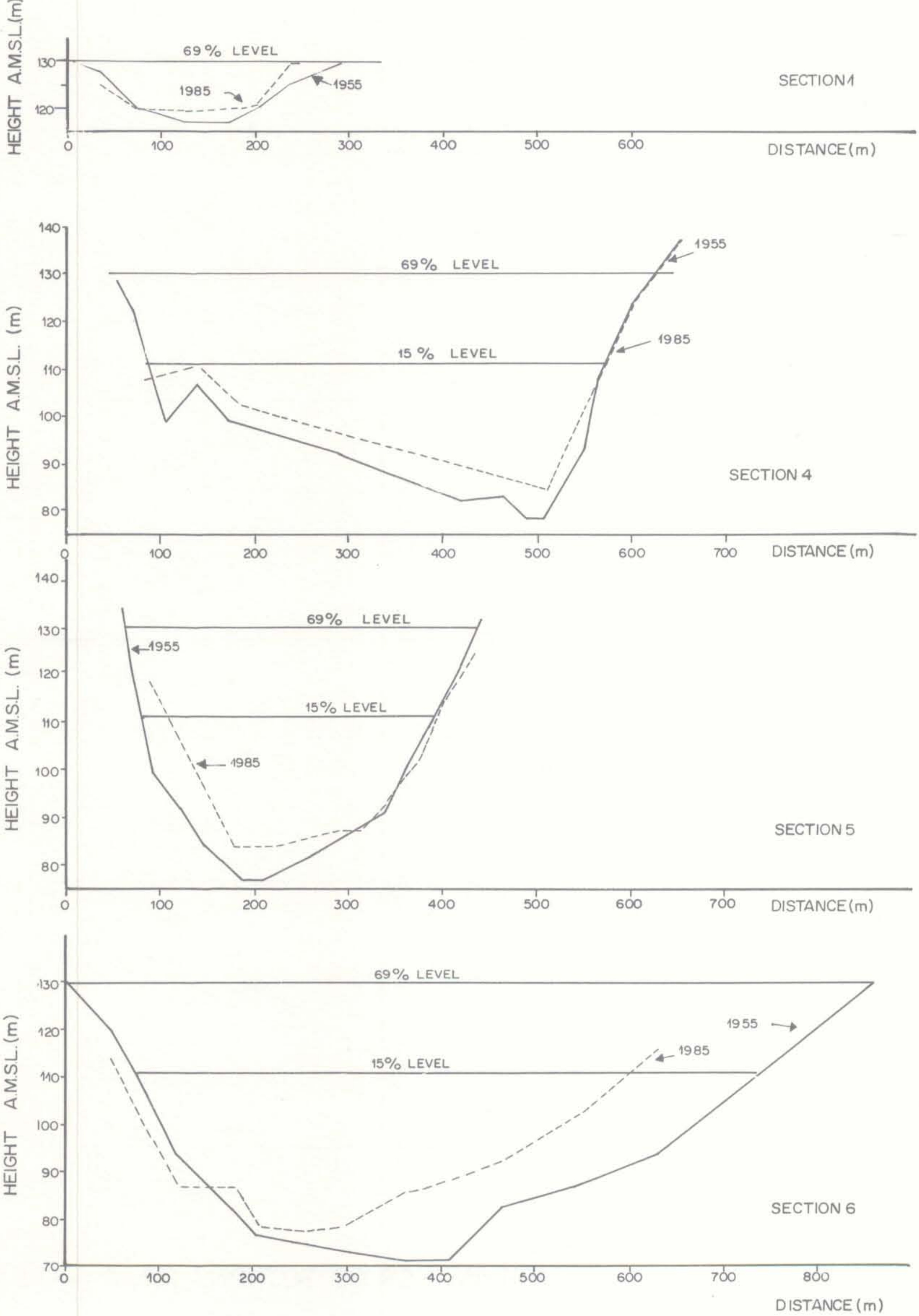


FIG. 7.4 C1 PONGOLAPOORT DAM : CROSS SECTIONS 1,4,5 AND 6

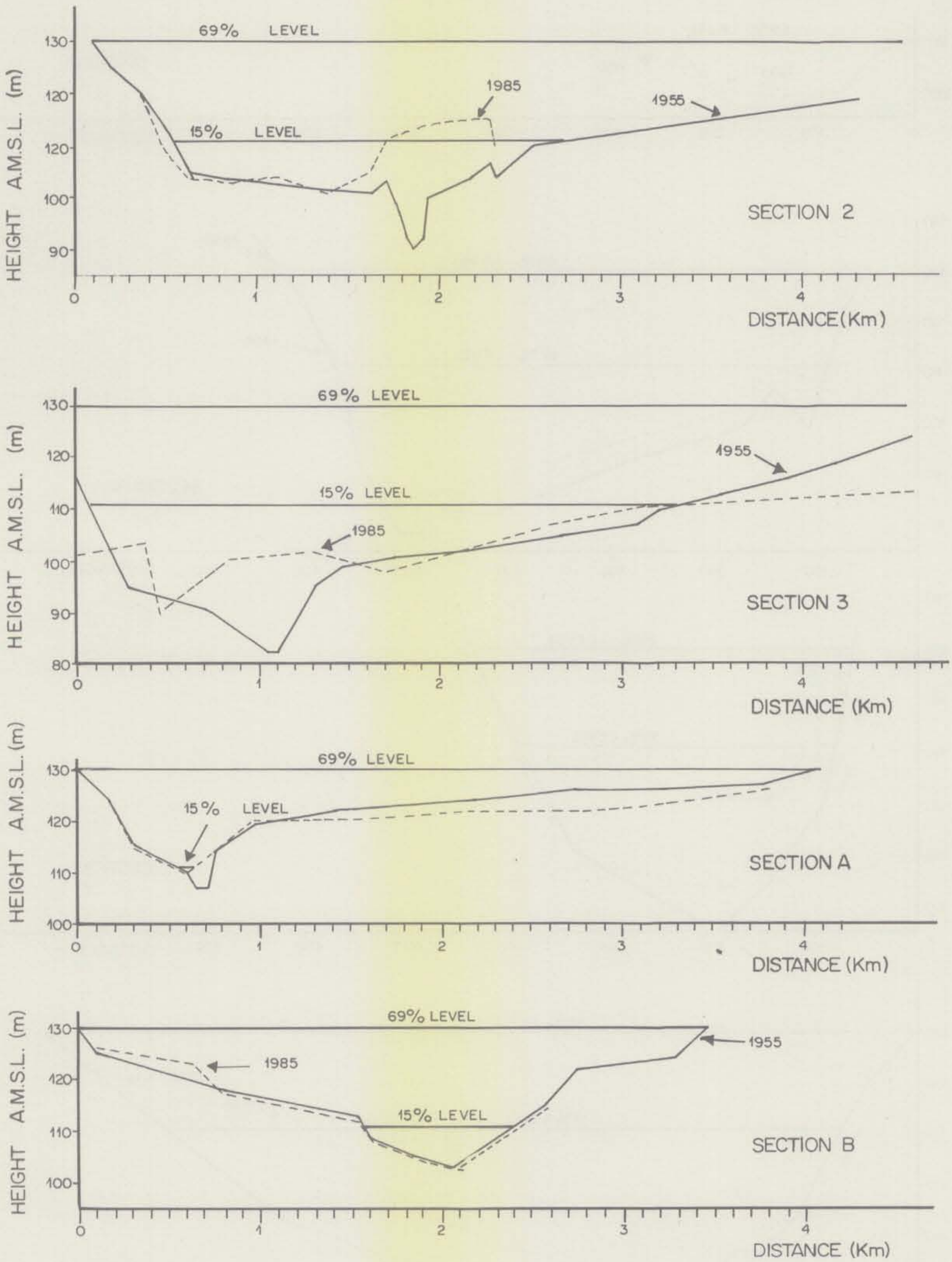


FIG. 7.4 C2 PONGOLAPOORT DAM: CROSS SECTIONS 2,3, A AND B

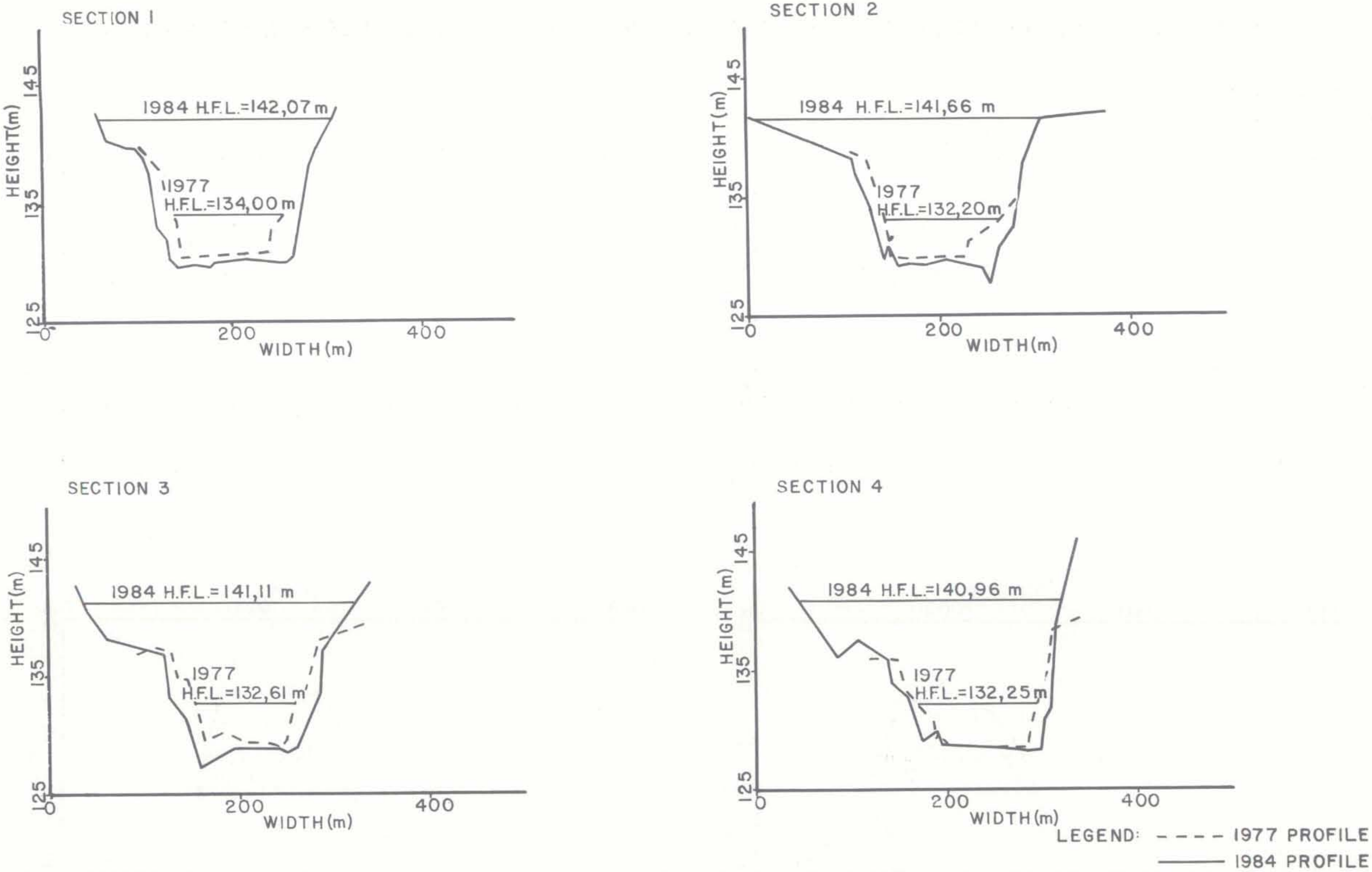


FIG.7.5 a COMPARISON OF CROSS SECTION CHANGES AT SITE 13: WHITE MFOLOZI RIVER

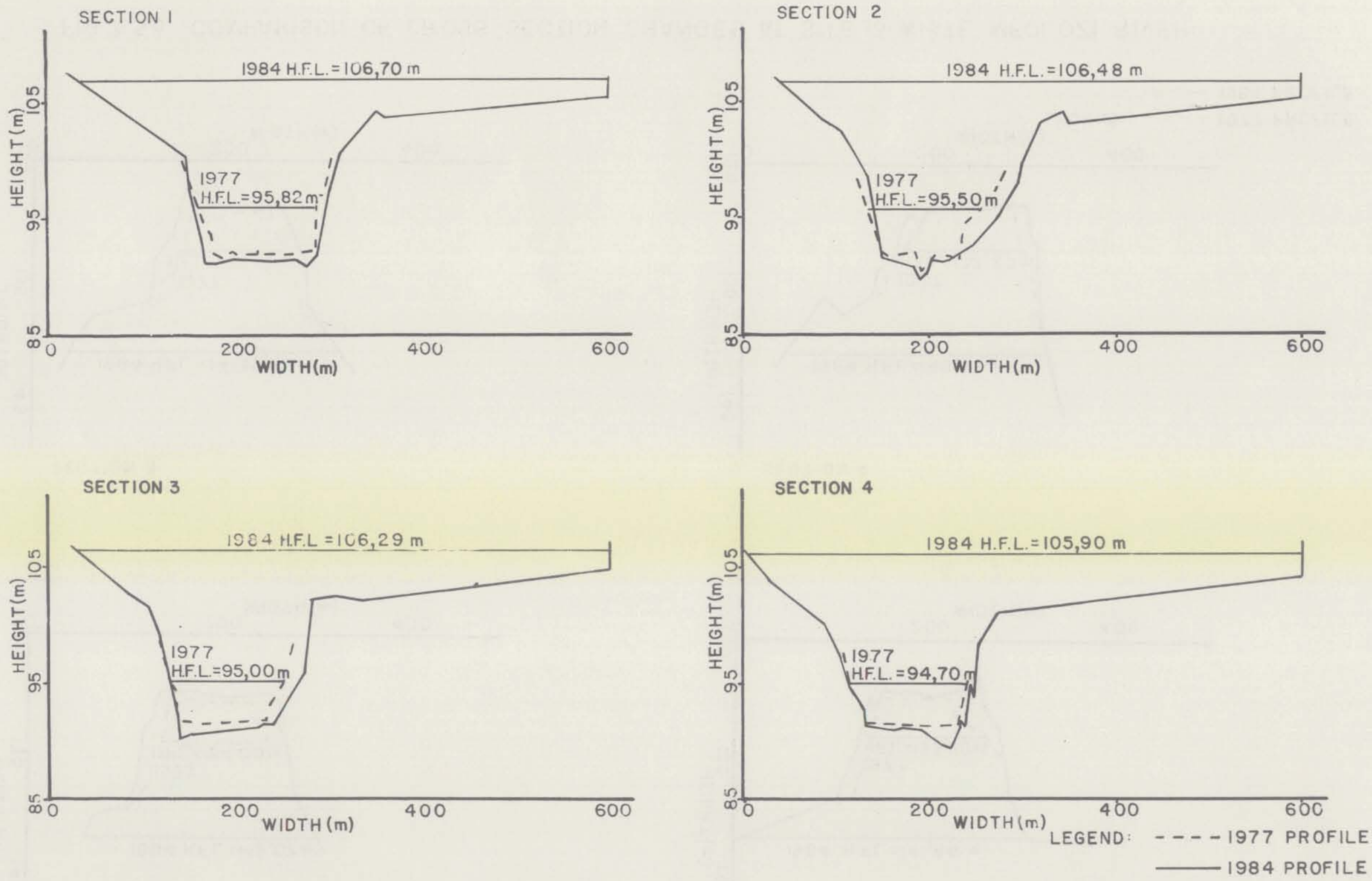


FIG.7.5 b COMPARISON OF CROSS SECTION CHANGES AT SITE 17: BLACK MFOLOZI RIVER

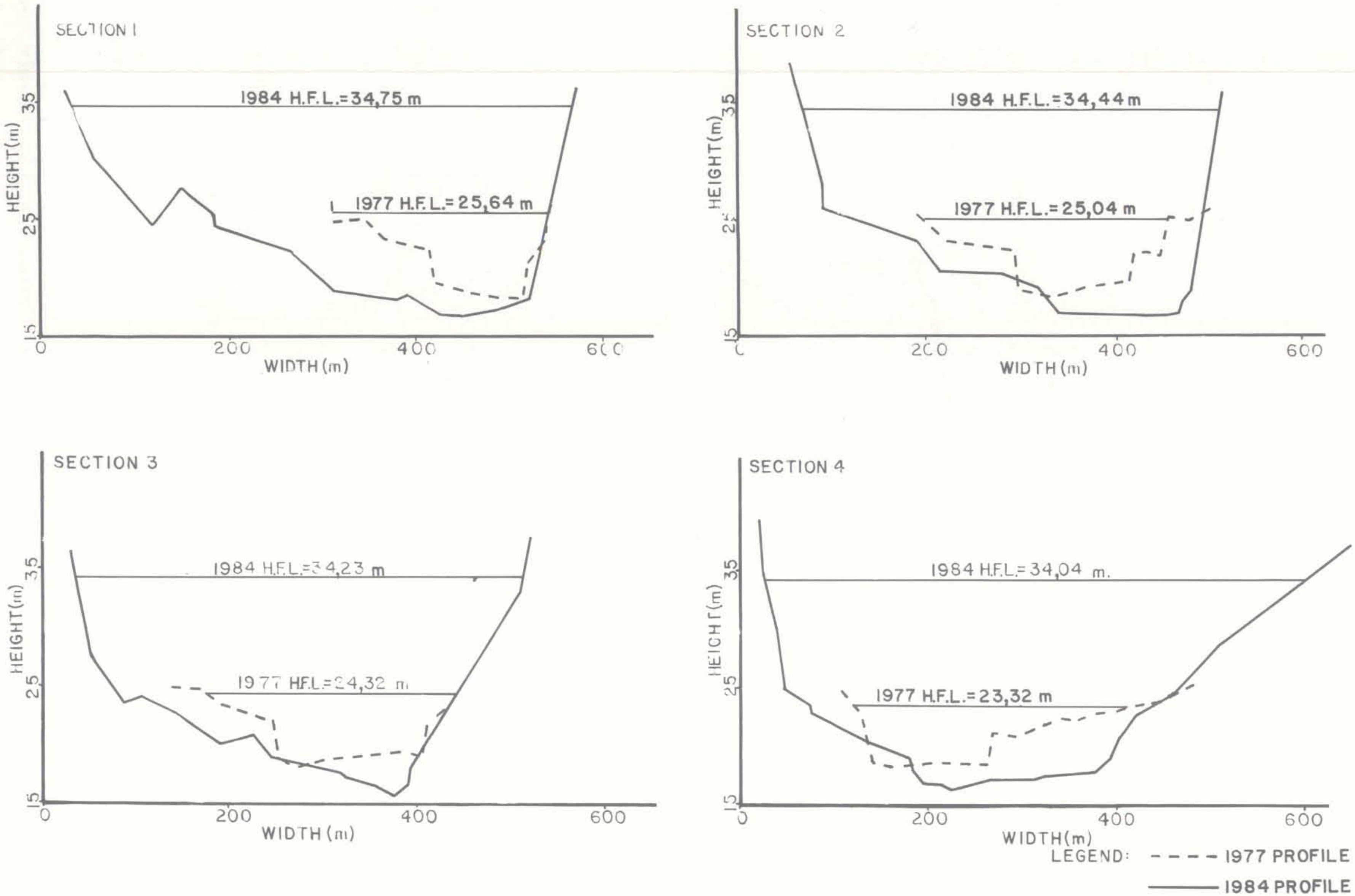


FIG.7.5 c COMPARISON OF CROSS SECTION CHANGES AT SITE 18: MFOLOZI RIVER

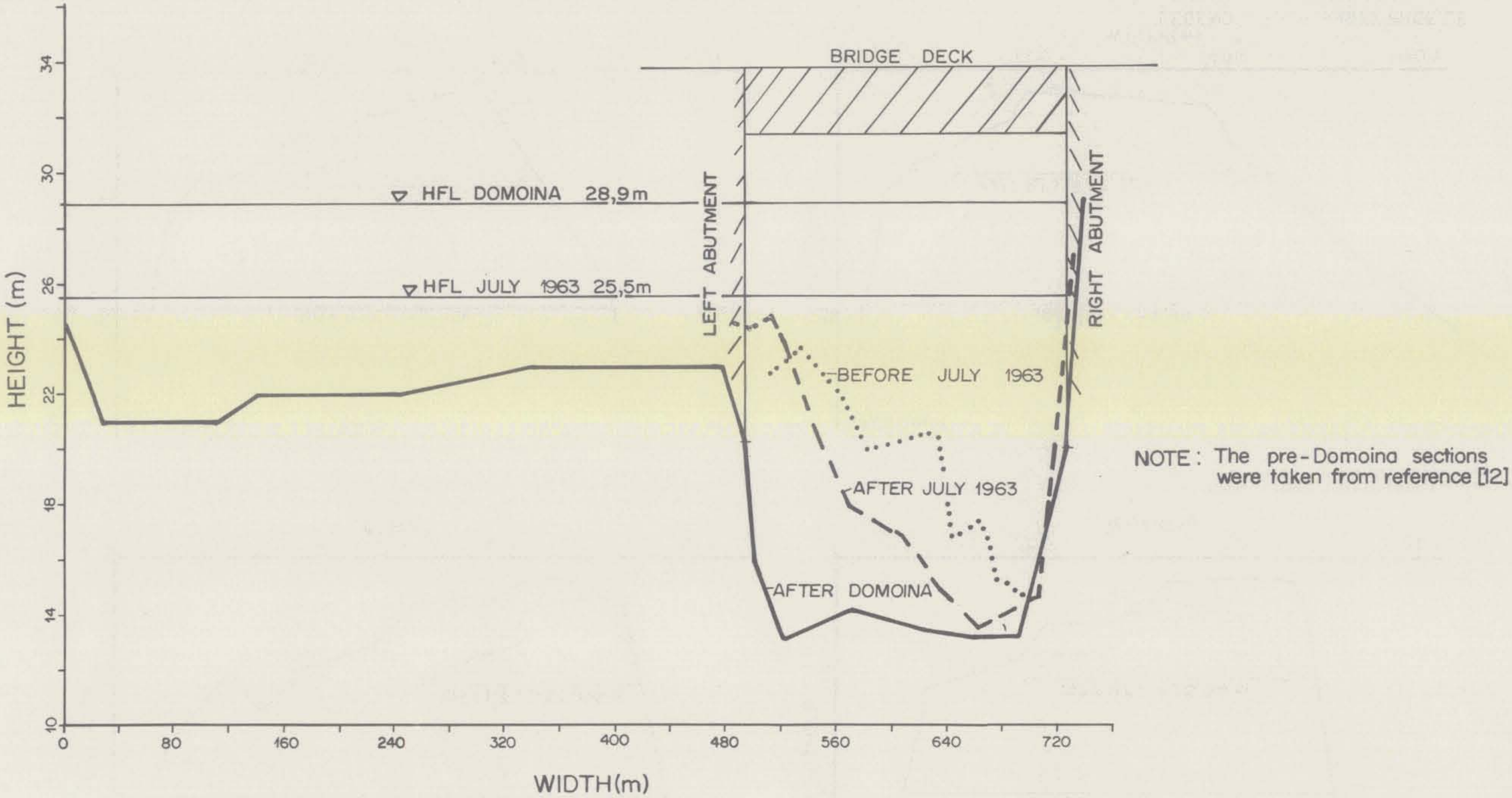
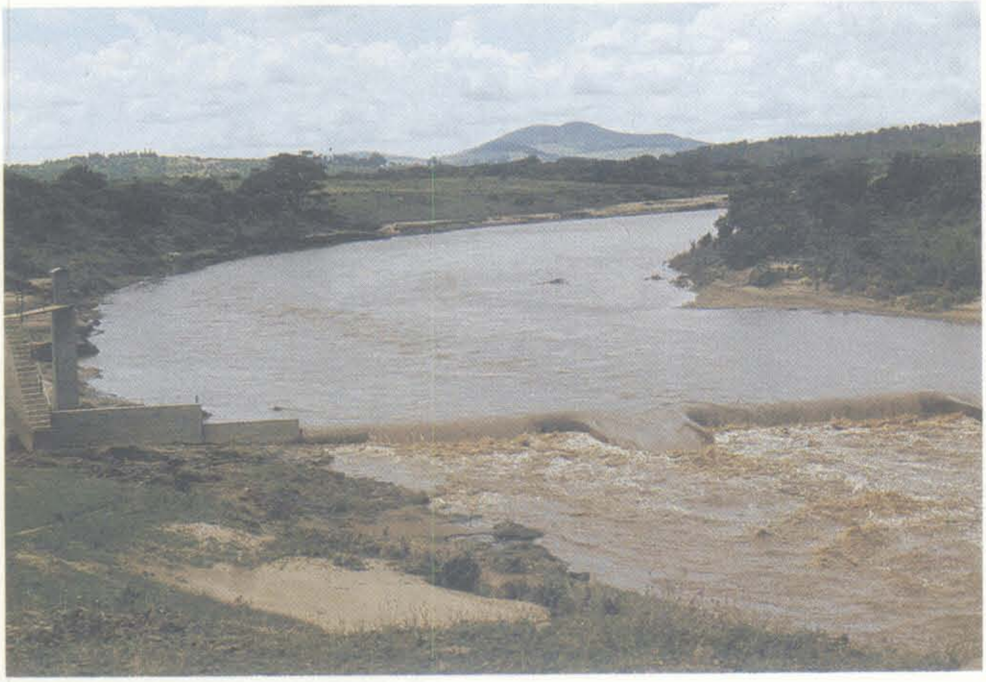


FIG. 7.6 COMPARISON OF SURVEYED SECTIONS AT SITE 19 (MFOLOZI AT THE N2 BRIDGE)

1. Satellite photograph taken on 1984.01.27 at 12h00 GMT (Pretoria Weather Bureau)



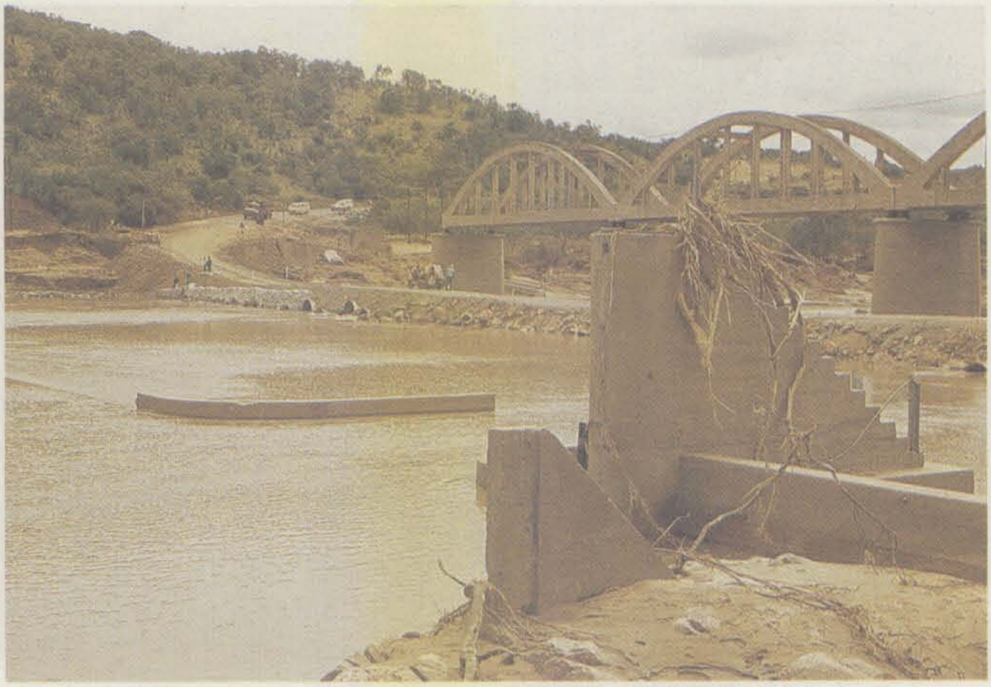
2. Mhlatuze River: upstream view of gauging weir W1M09 and slope area reach, Site 8

3. White Mfolozi River: flood peak conditions with waves of ~ 2 m near Site 12 (P. Berridge, KwaZulu, Department of Agriculture and Forestry)

4. White Mfolozi River: bridge near Ulundi, rising flood, Site 12

5. White Mfolozi River: bridge near Ulundi, deck is being washed away, Site 12 (P. Berridge)

6. White Mfolozi River: bridge near Ulundi during flood peak conditions, Site 12 (P. Berridge)



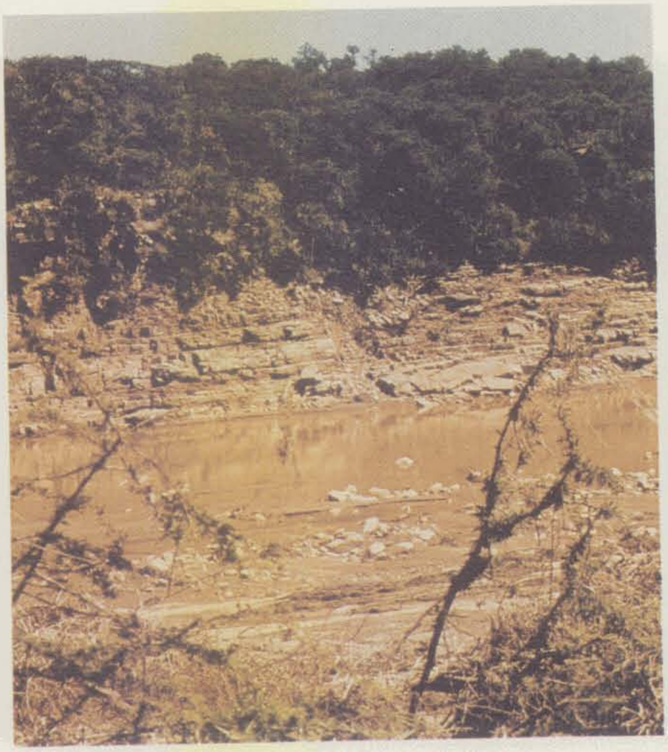
7. White Mfolozi River: bridge near Ulundi and gauging station W2M05 after Domoina, Site 12

8. White Mfolozi River: bridge near Ulundi after Domoina, Site 12

9. White Mfolozi River: bank erosion, channel and flood plain sediment deposits. Umfolozi Game Reserve, Site 13

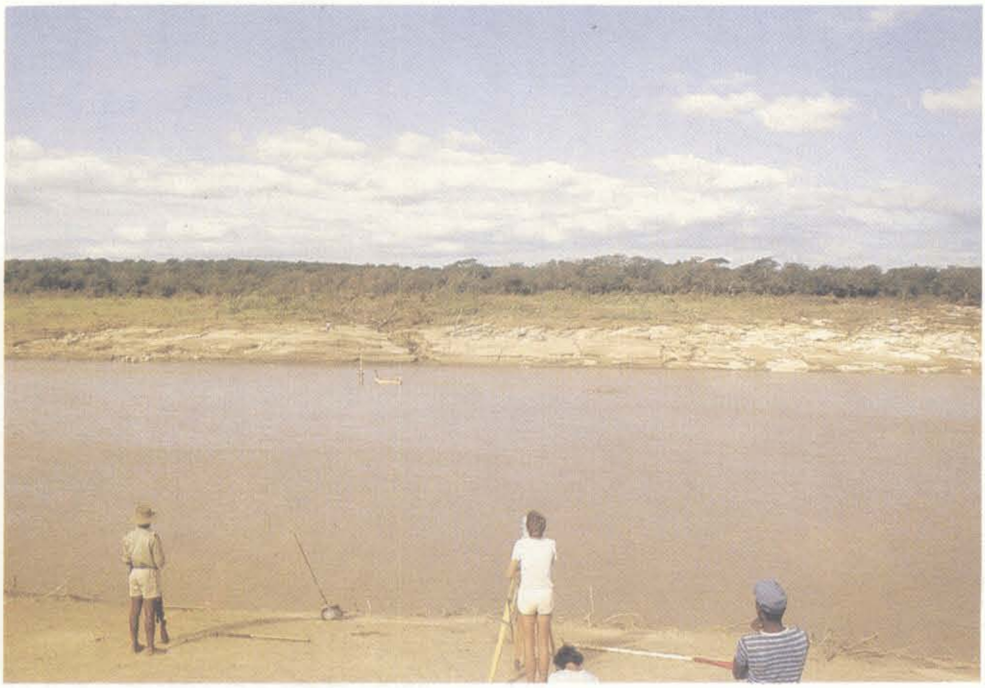
10. Bizamkulu River: channel roughness ~ 0,75 m, Site 15

11. Black Mfolozi River: channel roughness ~ 0,55 m, Site 14

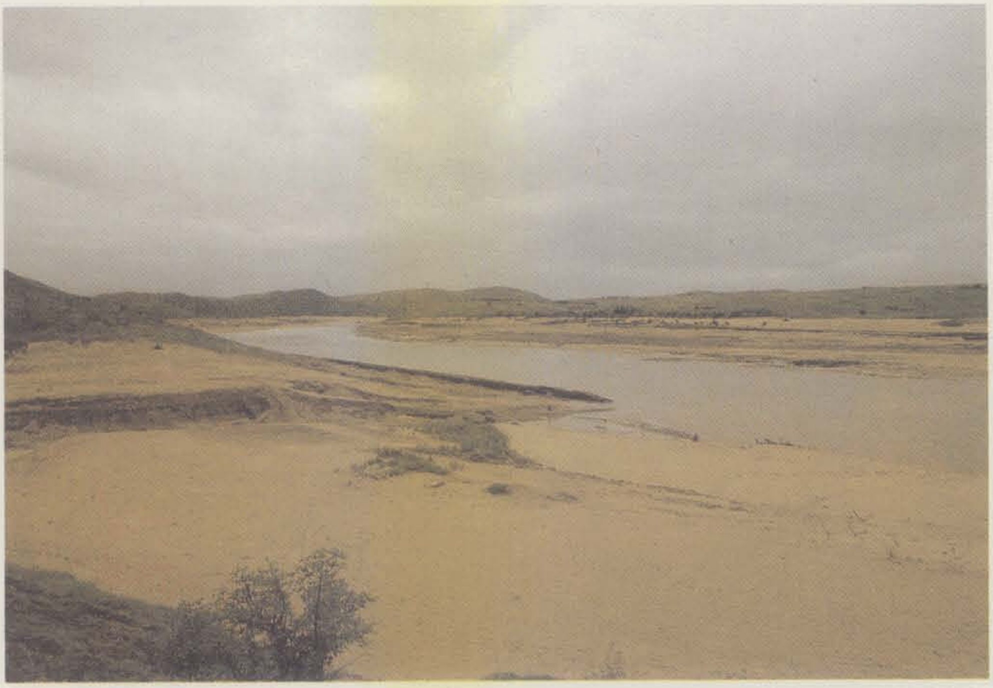


12. Black Mfolozi River: steep rocky bank, roughness ~ 2 m, Site 16

13. Black Mfolozi River: general downstream view of Site 17 in the Umfolozi Game Reserve



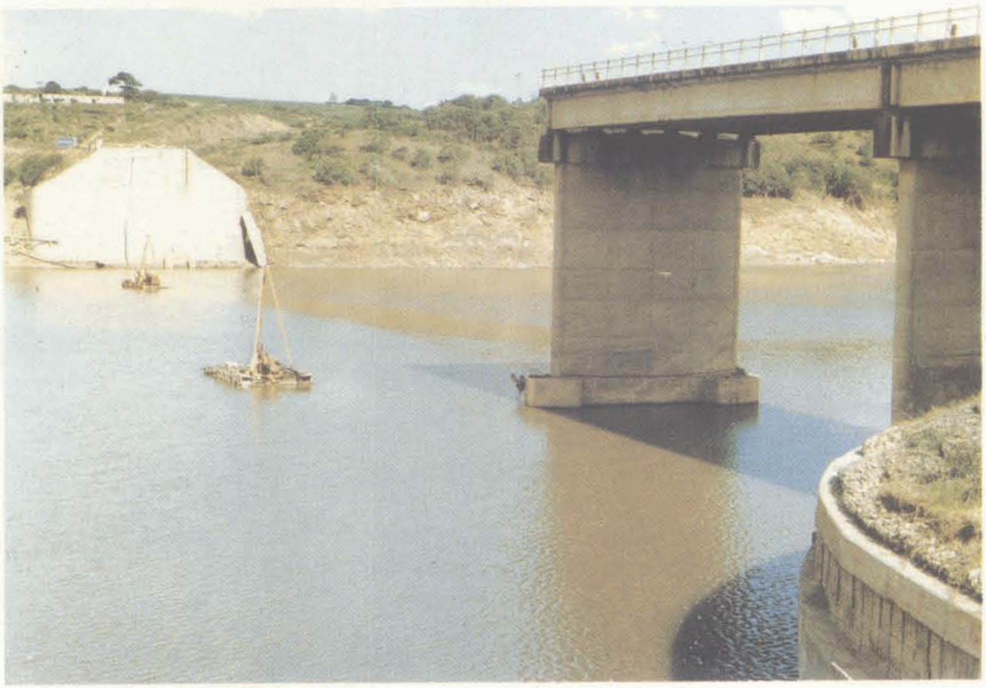
14. Black Mfolozi River: cross-section survey at Site 17 in the Umfolozi Game Reserve



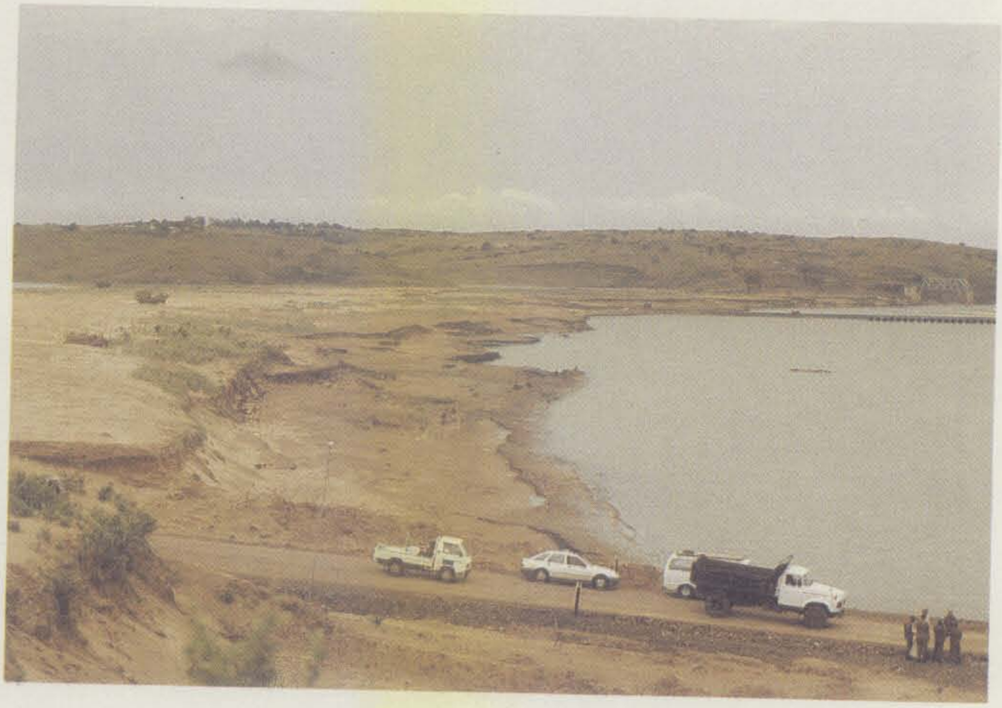
15. Mfolozi River: upstream view at Site 18

16. Mfolozi River: downstream view at Site 18.
In foreground tributary with sediment deposits.
Note flood line mark on right-bank hill

17. Mfolozi River: steep face of eroded sand bank, Site 18

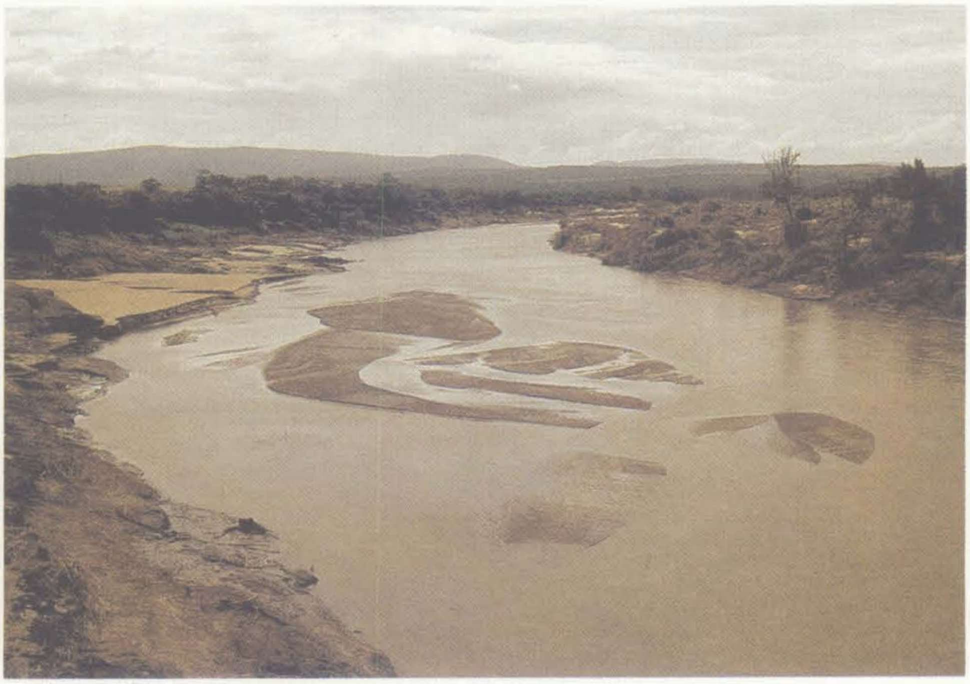


18. Mfolozi River: remnants of the N2 road bridge, view from left bank. Note denuded hillside with flood line mark, Site 19
(Department of Transport, Directorate of National Roads)



19. Mfolozi River: erosion and deposits along left bank downstream of the N2 road bridge

21. Mkuze River: destroyed flow gauging station W3M01, Site 22



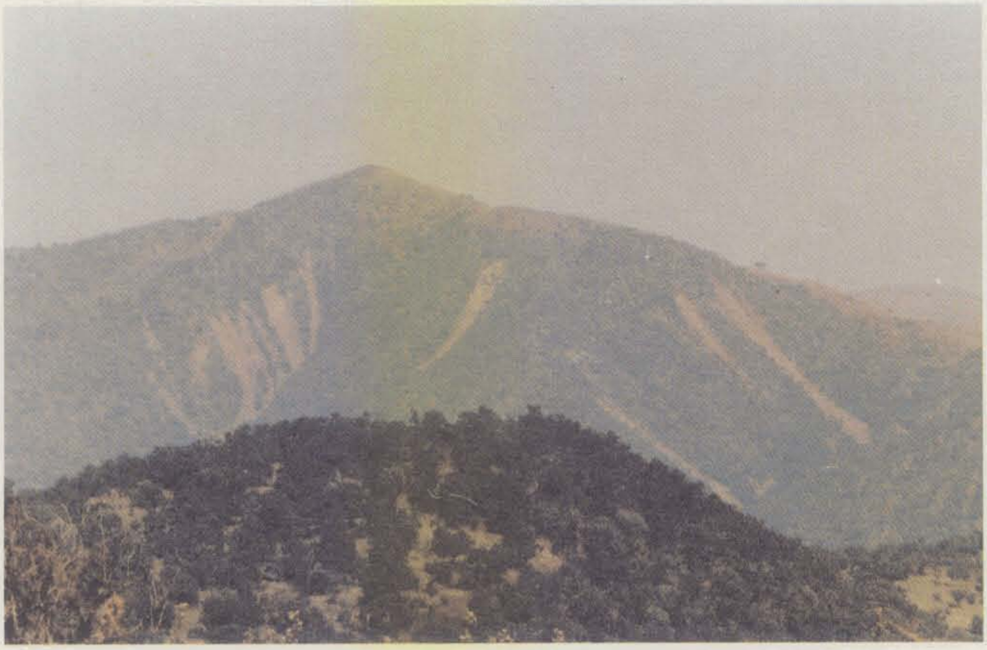
22. Mkuze River: upstream from the N2 road bridge

20. Mfolozi River: aerial view downstream of Site 19

23. Mkuze River: damaged N2 road bridge viewed from the right bank

24. Mkuze River: downstream close up picture of damaged N2 road bridge deck

25. Mkuze River: flattened trees and thin sediment deposits along left bank of Site 23



26. Landslides in the Pongola catchment near Commondale

27. Landslide in the Pongola catchment near Lüneburg

28. Pongolo River: Pongola - Magudu road bridge
before the 3rd flood peak at 14h00 on 31 January.
View from left side, upstream of Site 29
(Theo Hansmeyer, C.G. Smith Sugar Ltd, Pongola)

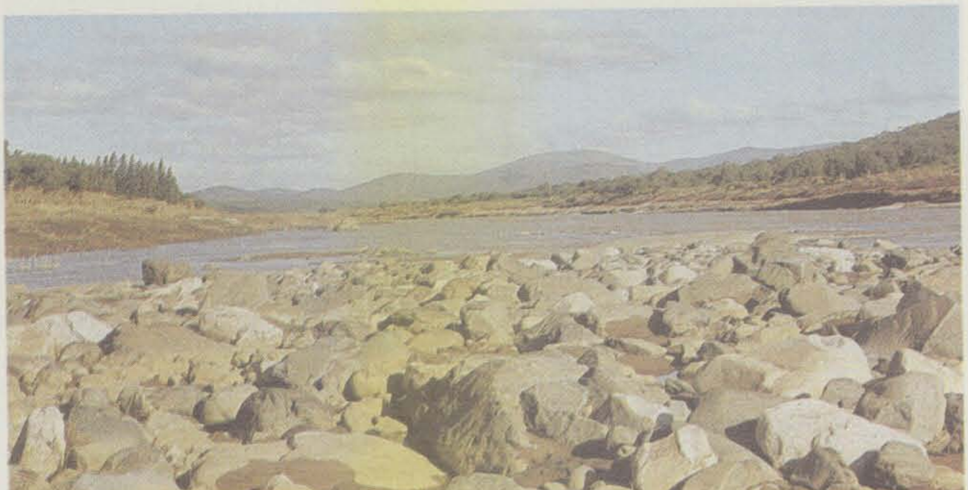
29. Pongolo River: Pongola - Magudu road bridge: damage to left bank approach. Picture was taken on 2 February, upstream of Site 29 (Theo Hansmeyer)

30. Rietspruit (tributary of Pongolo River): receding flood on 31 January (Theo Hansmeyer)

31. Mmyama: removal of debris from railway bridge
(Theo Hansmeyer)

32. Pongolo River: destroyed railway bridge at Horse Show Farm, 12 km upstream of Site 30

33. Pongolo River: upstream view of erosion along left bank, next to national road N2 between Pongola and Golela (Theo Hansmeyer)



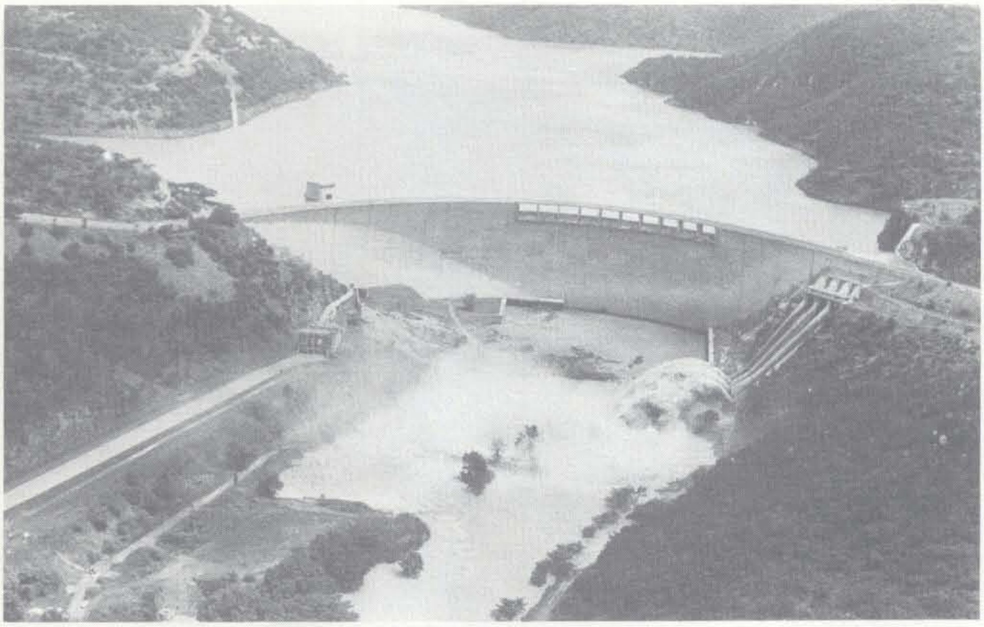
34. Pongolo River: downstream view of Site 30. Note flood line marks

35. Pongolo River: downstream view of Site 30.
Note flood line marks

36. Pongolo River: rising flood at the N2 road bridge. View towards the Transvaal side, upstream of Site 31 (Theo Hansmeyer)

37. Pongolo River: rising flood starts to overtop the N2 road bridge. View towards the Natal side upstream of Site 31 (Theo Hansmeyer)

38. Pongolo River: 2 to 3 m high waves near destroyed N2 road bridge during receding main flood peak. Picture was taken at 09h30 on 31 January, upstream of Site 31 (Theo Hansmeyer)



41. Pongolapoort Dam: general view during flood release of ~ 1 000 m^3/s on 8 February 1984, Site 32 (W.C.S. Legge, Chief Engineer Design, Department of Water Affairs)

42. Pongolapoort Dam: downstream view of jet plunge pool with damage caused by release, Site 32 (W.S. Croucamp, Chief Engineer Design, Department of Water Affairs)

39. Pongolo River: remnants of the N2 road bridge after Domoina, upstream of Site 31

40. Pongolo River: downstream view. Note flood line along denuded hillside, downstream of Site 31

43. Pongolapoort Dam: testing of modified chutes with a release of 400 m^3/s and rip-rap protection of damaged right-bank, Site 32 (D.R. Clark, Engineer, Department of Water Affairs)

44. Ngwavuma River: upstream view of an ideal slope-area reach, Site 33

45. Great Usutu River: debris left on upstream side of bridge on the Manzini-Mahamba road, upstream of Site 47 (C.J. Rodda of Van Niekerk, Kleyn and Edwards, Consulting Engineers)

46. Great Usutu River: downstream side of bridge on the Manzini-Mahamba road with submerged low-water bridge, upstream of Site 47 (C.J. Rodda)

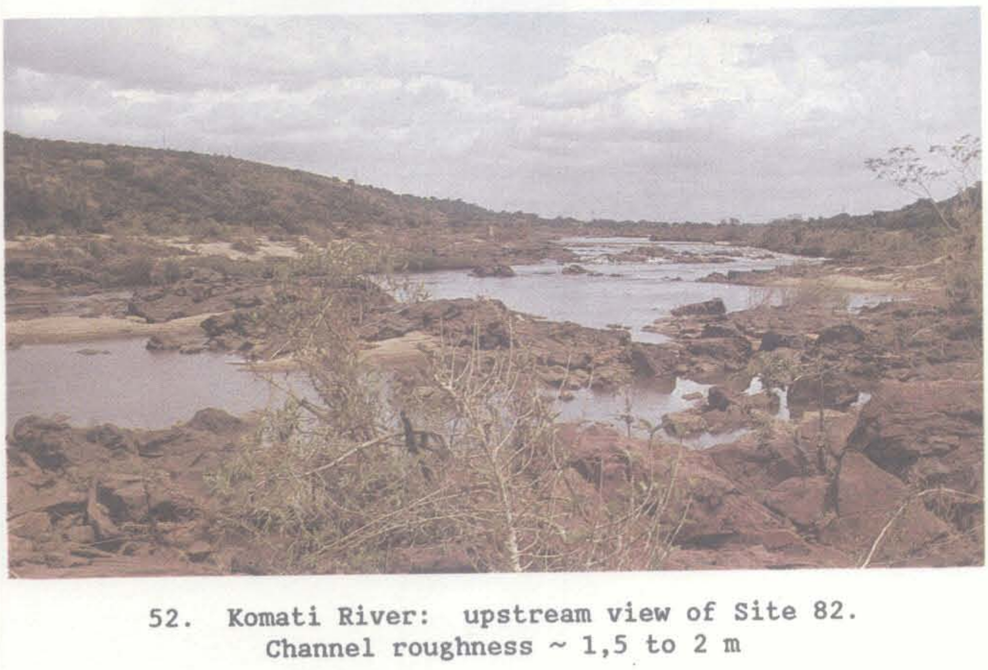
49. Komati River: Tonga Rapids during receding floods on 3 February, Site 57

50. Mlumati River: Very thick bush at Site 59

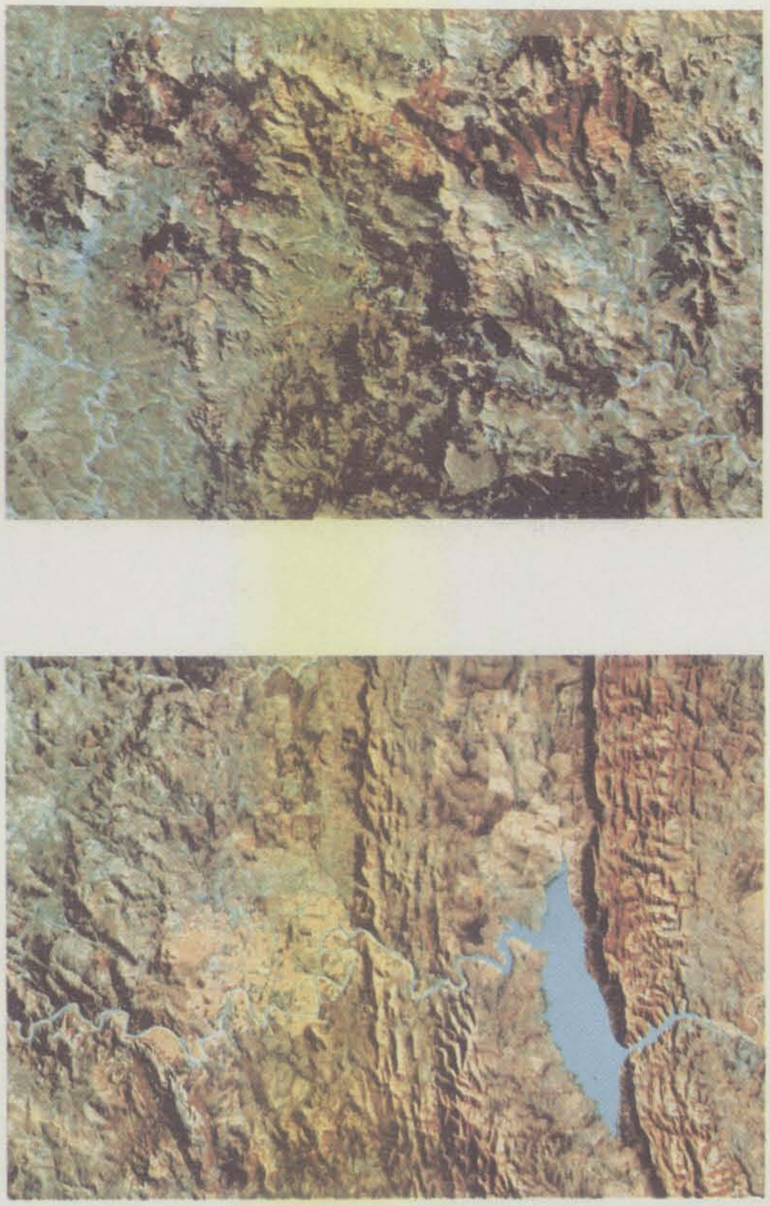
47. Great Usutu River: destroyed road bridge at Big Bend, downstream of Site 48 (C.J. Rodda)

48. Komati River: downstream view of a very good slope-area reach, Site 56

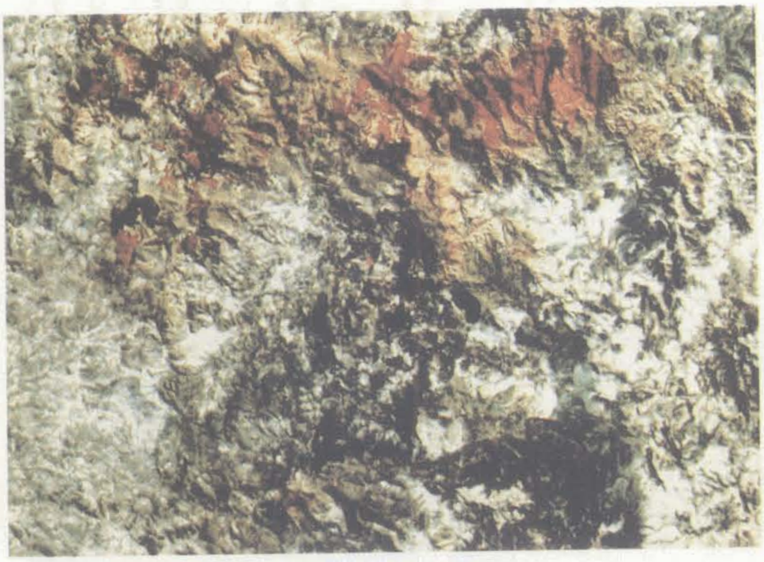
51. Komati River: general view of Site 82 from the right bank, just downstream of confluence with the Crocodile River



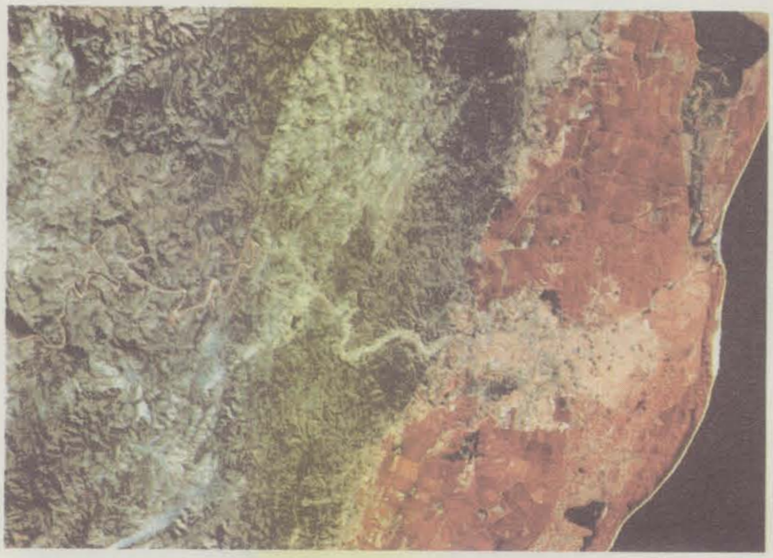
52. Komati River: upstream view of Site 82. Channel roughness ~ 1,5 to 2 m

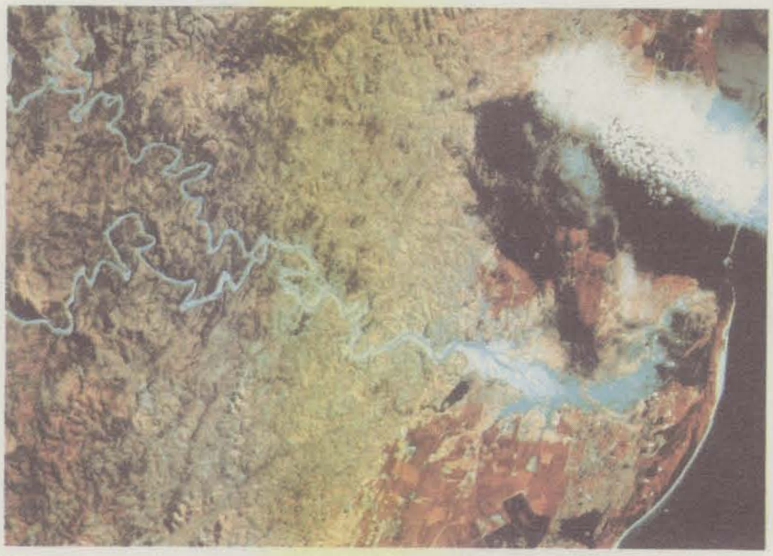


53. Pongolapoort Dam area: pre- and post Domoina LANDSAT images (Satellite Remote Sensing Centre of the National Institute for Telecommunications Research)



54. Black Mfolozi catchment at Site 16: pre- and post Domoina LANDSAT images (Satellite Remote Sensing Centre of the NITR)





55. Lower Mfolozi area: pre- and post Domoina LANDSAT images
(Satellite Remote Sensing Centre of the NITR)

APPENDIX 1: DAILY RAINFALL DATA

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
239/002	29	32	30	01	Dargle	14		6	25	20	1	52	
133	29	43	30	05	Vaucluse	0			80	12		92+	
472	29	52	30	16	Richmond	2		7	47	23		77	
518	29	38	30	18	Edendale	-		7	15	16		38	
585	29	45	30	20	Baynesfield Estate	21		17	39	19	1	76	
604	29	34	30	21	Allerton	-		10	19	38		67	
784	29	34	30	27	Kensington	21		30	21	47		98	
240/022	29	52	30	31	Eston	7		10	17	25		52	
028	29	58	30	31	Mid-Illovo	57		12	26	35		73	
031	29	31	30	32	Windy Hill	19		32	25	47		104	
073	29	43	30	33	Camperdown	25		18	24	39	2	83	
U2 R02	29	35	30	37	Nagle Dam	14		24	22	50		96	Dam
240/381	29	51	30	43	Shongweni	17		59	13	43	2	117	
389	29	59	30	43	Umbumbulu	11		87	41	42		170+	
404	29	44	30	44	Bothas Hill	-		57	19	38	14	128	
564	29	54	30	49	Intake Weir	48		70	16	87	2	175	
586	29	46	30	50	Kloof	23		65	28	72	3	168	
683	29	53	30	53	Queensburgh	3		108	28	82	2	220	
716	29	56	30	54	Umlaas Waterworks	51		52	17	90	3	162	
738	29	48	30	55	Durban Heights	20		44	26	75	6	151	
753	29	33	30	56	Ndwedwe	35		122	47	129		298	
862	29	52	30	59	Durban-Stella	80		50	25	60		135	
887	29	47	31	00	Effingham	0	17	65	70	24		176	
891	29	51	31	00	Durban - Botan Gardens	56		66	38	68	1	173	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
241/019	29	49	31	01	Durban - Florida Road	55		67	35	64	1	167	
U3 R01	29	36	31	03	Hazelmere (Mdloti)	51			114	46	85	245	Dam
241/103	29	43	31	04	Cornubia	6		30	58	110	17	215	
131	29	41	31	05	Blackburn	33	63	47	104	15	2	230	
302	29	32	31	11	Frasers	4	75	60	66	7	1	209	
V7 R01	29	02	29	52	Wagendrift	19		1	16	8	1	26	Dam
U2 R01	29	30	30	12	Midmar	32		29	20	9	1	59	Dam
V2 R01	29	10	30	17	Craigie Burn	19		19	30	18		67	Dam
269/611	29	11	30	21	Rietvlei	14		27	34	39	1	101	
647	29	17	30	22	Mbona MTN Estate	35	30	33	101	3		167+	
712	29	22	30	24	Clan Syndicate	29	23	26	45	2	1	97	
775	29	25	30	26	Cramond	4	22	22	29	2	1	76	
U2 R03	29	26	30	26	Albert Falls	23		12	39	28		79	Dam
270/021	29	21	30	31	New Hanover	38	15	5	32	0	46	98	
119	29	29	30	34	Windy Hill	15		44	33	61	3	141	
282	29	12	30	40	Groenkop Estate	0	41	58	38			137	
544	29	04	30	49	Boscombe	42	35	102	76	5		218	
722	29	02	30	55	Glen Eland	15	30	121	74	8		233	
271/099	29	09	31	04	Mapumulo	14		91	75	72	5	243	
420	29	30	31	14	Umhlati Beach	18		96	46	55	3	200	
500	29	20	31	17	Stanger	42		63	46	64	5	178	
702	29	12	31	24	Newark	51		73	51	71	17	212	
272/121	29	01	31	35	Gingindhlovu	28	2	89	92	116	13	312	
127	29	07	31	35	Amatikulu	37		41	51	50	23	165	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
272/272	29	02	31	40	Fairbreeze Estates	46	15	11	118	144	54	342	
V1 R02	28	46	29	18	Driel	24			8	5		13	Dam
V1 R01	28	41	29	31	Spionkop	25	9	1	15	4		29	Dam
301/692	28	32	30	24	Enhlanhleni	64		51	137	45	2	235	
751	28	31	30	26	Sutherland	-		44	134	68	4	250	
302/418	28	58	30	44	Springrove Estate	50		38	98	44		180	
626	28	58	30	51	Krankskop	25		26	119	33	8	186	
687	28	57	30	53	Linklater	12	1	32	100	27	6	166	
699	28	39	30	54	Qudeni Bos	80		178	140	63		381+	
303/127	28	37	31	05	Nkandla	17		39	133	93		285	
695	28	35	31	24	Melmoth	45	40	145	150	60	9	404	
730	*28*	*40*	*31*	*25*	*Zietover*	43		97	157	160	23	437	
W1 R01	28	46	31	29	Goedetrouw	17		70	1230	111	14	325	Dam
304/426	28	36	31	45	Ntambanana	20		159	171	33		363	
446	28	56	31	45	Mtunzini	31		71	93	139	25	328	
593	28	53	31	50	Port Durnford	45		37	121	194	73	425	
727	28	37	31	55	Makhuba	*77*		*16*	*167*	*523*	*244*	*950*	*Too high*
736	28	46	31	55	Empangeni	91		33	134	267	62	496	
822	28	42	31	58	Kulu Halt	84		30	65	460		555+	
305/037	28	37	32	02	Fairview	70		13	47	360	167	587	
168	28	47	32	06	Richards Bay			12	46	316	131	505	
308	28	38	32	11	KwaNbonambi	59		19	35	337	107	498	
336	28	36	32	12	Langepan	135		3	40	440	141	624	
335/091	28	01	30	04	Dannhauser	33		12	68	29		109	
169	28	19	30	06	Wasbank	86		38	61	27		126	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
335/215	28	05	30	08	Hattingspruit	20		39	95	60		194	
400	28	10	30	14	Dundee	15		30	99	37		166	
620	28	20	30	21	Swartwater	48		25	129	50		204+	
336/283	28	13	30	40	Nqutu	150		32	157	72	1	262	
F1	28	03	30	49	Roodepoort							300+	
F2	28	06	30	52	Palmietfontein							314	
F3	28	05	30	55	Lekkerwater							453	
337/006	28	06	31	01	Goedgeloof	12		28	216	50	2	296	
143	28	23	31	05	Babanango	7		55	201	155		411	
F4	28	23	31	05	Babanango							455	
F5	28	23	31	05	Babanango							450	
F6	28	28	31	05	Welverdiend							478	Also 337/148
F7	28	13	31	11	Langgewacht			55	400	275		730	
F8	28	01	31	12	Doornhoek 204							350	
F9	28	01	31	12	Doornhoek 204							313	
F10	28	23	31	13	Pembeni			55	173	81	44	353	
337/431	28	11	31	15	Surprise Store	33		58	426	243	8	735	
628	28	28	31	21	Mtanjaneni	6		35	210	152	10	407	
338/380	28	20	31	43		20	4	35	124	17		180+	
524	28	14	31	48		15	10	30	235	215		490	
F11	28	08	31	53	Hlabisa-Hosp.							450	
338/668	28	08	31	53	Hlabisa	56	11	43	206			260+	
714	28	24	31	54		22	6	9	112	223		350	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
339/065	28	05	32	03	Hluhluwe Game Reserve	73	20	59	210	196	32	517	
157	28	07	32	06		44	13	58	220	133		424+	
212	28	02	32	08		30	20	57	107	215		399+	
F12	28	30	32	10	Mfolozi							486+	
F13	28	30	32	10	Mfolozi Lot 336					372		486	
F14	28	27	32	11	Mtubatuba Sugar Mill					330		409	
F15	28	28	32	11	Mtubatuba					328		434	
W3 R01	28	07	32	12	Hluhluwe	15	14	23	87	197	26	347	Dam
339/352	28	27	32	12	Kangela	21	5	7	31	305	28	376	
F16	28	27	32	13	Umfolozi Lot 74					290		369	
339/415	28	25	32	14	Hill Farm	16	4	10	42	323	46	425	
F17	28	01	32	15	Emoyeni							432	
F18	28	01	32	16	Hluhluwe							425	
339/523	28	13	32	18	Nyalazi	28		14	27	350	99	490	
F19	28	26	32	18	Monzi Sonrooy			10	36	416	95	557	
F20	28	27	32	18	Monzi Kirk Co.							649	
339/538	28	28	32	18	Uloa	16		10	31	420	92	553	
681	28	21	32	23	St. Lucia Estuary	24	1	6	24	497	92	620	
734	28	14	32	25	Makakatana	29	4	6	25	390	108	533	
F21	28	22	32	25	St. Lucia Estuary					428		590+	
339/756	28	06	32	26	Fanieseiland	60		13	23	290		326	
856	28	16	32	29	Estuary	42		11	20	548	123	702	
F22	28	09	32	33	Eastern Shores State Forest					266		431	
V3 R01	21	57	29	57	Chelmsford	44		7	41	32		80	Dam
371/437	27	47	30	15	Waterval	24		28	82	69	11	190	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
371/579	27	39	30	20	Utrecht	22		42	135	84	40	301	
706	27	46	30	24	Waaihoek	24		62	116	108		286	
F23	27	48	30	29	Rusthof							360	
F24	27	49	30	29	Baltusspruit							350	
F25	27	34	30	31	Waterval		80	165	128			373	
F26	27	37	30	31	Zoekmelk							610	
F27	27	45	30	32	Goedehoop							383	
F28	27	45	30	32	Avondsrust					250		360	
F29	27	46	30	32	Goedgelof							340	
372/056	27	56	30	32	Kingsley	45		33	145	75		253	
F30	27	58	30	32	Strydfontein							210	
F31	27	51	30	33	Rehlingen							245	
F32	27	53	30	34	Rooikoppe							300	
F33	27	53	30	35	Bloodrivier							319	
F34	27	55	30	36	Overschot							300	
F35	27	54	30	38	Sweethome			38	189	50		277	
F36	27	41	30	41	Waverley							531	
372/361	27	31	30	43	Marthinusdrift	39		80	209	155		444+	
F37	27	48	30	43	Saaifontein							385	
F38	27	41	30	47	Grootgeluk							532	
372/496	27	46	30	47	Vryheid	85	100	84	123	162	6	475	
602	27	32	30	51		35		78	260	118		456+	
F39	27	53	30	57	Waterval				334			610	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
F40	27	44	30	58	Nyembe			75	263	120		458	
372/852	27	42	30	59	Hlobane				269	110		379+	
373/058	27	58	31	02	Gluckstadt			84	315	158		557+	
F41	27	58	31	02	Hardbetaald							606	
F42	27	41	31	04	Coronation							456	
F43	27	49	31	04	Bloemendal 18							714	
373/110	27	50	31	04	Bloemendal	47		105	363	139	8	615	
F44	27	47	31	05	Mount Mgwibi							625	
F45	27	45	31	06	Kromellenboog							446	
373/169	27	49	31	06	Boshoek (Natal Anthr. Coll.)	37		209	354	355	6	924	
F46	27	36	31	07	Kruisfontein							504	
F47	27	49	31	07	Boshoek				± 300			± 650	
F48	27	44	31	08	Donkerhoek							383	
F49	27	41	31	10	Skutari				225			431	
F50	27	35	31	11	Bedrog							400	
373/329	27	59	31	11	Vlakfontein	25	1	86	255	147	7	496	
F51	27	37	31	12	Welverdiend				140			350	
F52	27	38	31	14	Cornelia				± 400			670	
F53	27	58	31	14	Welgevonden							625	
F54	27	37	31	15	Susanna							500+	
373/485	27	35	31	17	Louwsburg	68			181	245	113	539	
F55	27	36	31	18	Smaldeel		20	215	280	195	5	715	
F56	27	36	31	21	Joffre							730	
F57	27	36	31	23	Tevrede		42	100+	197+	189	8	536+	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
F58	27	40	31	23	Wykom			122	232	125	12	491	
373/680	27	50	31	23	Ngomi	68		172	288	164	10	634	
F59	27	44	31	25	Pambaan				100	188	30	318	
F60	27	42	31	27	Verdrukt							260	
F61	27	37	31	28	Mooiklip							500	
F62	27	34	31	30	Paradise 54							460	
F63	27	35	31	32	Wonderboom							550+	
F64	27	34	31	35	Goedehoop							424	
F65	27	34	31	37	Chichester							400	
F66	27	36	31	37	Vergelegen 260							270	
F67	27	31	31	39	Arizona							384	
F68	27	32	31	39	Magudu SAP							406	
F69	27	32	31	39	Magudu Land-dros			215	126	93	5	440	
F70	27	32	31	39	Mgambo				138			465	
F71	27	32	31	39	Magudu Lot 23							535	
F72	27	33	31	39	Magudu Hill							625	
F73	27	54	31	39	Nongoma	-	10	75	164	125	28	402	
F74	27	38	31	43	Panbult							500	
374/402	27	42	31	44	Zilverhout	25	25	80	161	25	27	318	
F74A	27	32	31	45	Bedrog							425	
375/124	27	34	32	05	Ubombo	51		145	200	114	37	496	
366	27	36	32	13	Mkuze Game Re-serve	18	27	59	155	69	25	335	
688	27	58	32	23	False Bay Camp	21	15	15	55	220	6	311	
376/220	27	40	32	38		34			128	215	(155)		498
407/148	27	28	30	05	Barrowfield	67		71	91	99	16	277	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
407/418	27	28	30	14	Groenvlei	38		60	90	68		218+	
639	27	09	30	22	Groot Rietvlei	37		52	72	76	25	225	
730	27	10	30	25	Dirkiesdorp	31		75	78	52	4	209	
F75	27	18	30	28	Goedgevonden					174		532	
F76	27	06	30	29	Amsterdam			100				225	
F77	27	17	30	29	Paandeplaas			238				539	
F78	27	21	30	29	Uitvlucht							425	
F79	27	05	30	31	Voorslag							225	
F80	27	16	30	32	La Belle Esperance							570	
F81	27	20	30	32	Lachkraal							406	
F82	27	25	30	32	Bella Vista					130		349	
F83	27	03	30	35	Anysspruit				141			344	
F84	27	18	30	35	De Molen							457	
F85	27	18	30	35	Koppje Alleen							640	
F86	27	23	30	35	Welbedacht				172			340	
F87	27	25	30	35	Schikhoek					150		350	
F88	27	19	30	38	Lüneburg					175		456	
F89	27	20	30	38	Lüneburg					180		535	
F90	27	21	30	38	Tamboekiesbult					150		370	
F91	27	23	30	38	Tamboekiesbult							351	
F92	27	03	30	40	Goedetrouw							535	
F93	27	19	30	41	Niebuhrsheim							619	
F94	27	25	30	43	Makateeskop			101	203	150	9	463	
F95	27	04	30	44	Weeber			195				410	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
F96	27	12	30	46	Wetterau							± 675	
F97	27	15	30	46	Tafelberg				260			652	
F98	27	18	30	48	Vryegunst							± 600	
F99	27	07	30	49	Anhang							475	
F100	27	10	30	50	Normandia				236			401	
F101	27	11	30	50	Normandia				285			525	
F102	27	11	30	50	Normandia				187			390	
F103	27	19	30	50	Vryegunst							640	
F104	27	16	30	51	Nederland				229			550	
F105	27	16	30	51	Nederland							629	
F106	27	14	30	52	Langfontein							± 800	
F107	27	15	30	52	Mooiplaas					322		574	
F108	27	17	30	53	Mooiplaas			147	273	182	16	618	
F109	27	15	30	55	Arcadia							486+	
F110	27	17	30	55	Witklip				302			669	
F111	27	17	30	55	Witklip							677	
F112	27	10	30	56	Lodewyk							595	
F113	27	19	30	56	Saaiplaas				300			640	
F114	27	02	30	57	Madola							486	
F115	27	18	30	57	Saaiplaas							750	
F116	27	18	30	57	Saaiplaas							722	
408/798	27	18	30	57	Saaiplaas	23		138	325	190	17	670	
F117	27	20	30	57	Bendor				± 400			± 800	
F118	27	13	30	58	Witrivier							537	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
F119	27	14	30	58	Witrivier							643	
F120	27	15	30	58	Witrivier							675+	
F121	27	04	30	59	Sandbank			200+	150+	100+		450+	
F122	27	11	30	59	Bloemendal							630+	
F123	27	07	31	01	Alma		36	225	245	60		566	
F124	27	14	31	01	Wagendrift				320			572+	
F125	27	16	31	01	Skaapkraal		155	282	325	50	38	± 850+	
F126	27	16	31	01	Skaapkraal							± 700	
F127	27	18	31	01	Mantoga			160	468	195	29	852	
F128	27	12	31	02	Kommetjie		169	(2 days)	304	96	6	575	
409/096	27	06	31	04	Mahamba	51		210	290	131	10	641	
F129	27	08	31	04	Alma				240			522	
F130	27	20	31	04	Honingkloof							590	
F131	27	14	31	06	Confidence				330			603	
409/320	27	20	31	11	Oranjedal			220	260	107		587	
/337	27	07	31	12	Nhangano		640	(3 days)		14	14	728	Swaziland
F133	27	16	31	12	Welkom		165	(2 days)	255	80	20	620	
409/375	27	15	31	13	Bergplaas	33	10	207	260	103	9	589	Also: F134
F135	27	15	31	15	Bergplaas				300			675	
409/862	27	22	31	29	Rhebokfontein	71		164	272	296	8	740	
410/132	27	12	31	35	Hluti	49		240	160	100	25	525	Swaziland
F136	27	23	31	37	C.G. Smith Sugar Ltd							388	
F137	27	23	31	37	Pongola							325+	
F138	27	23	31	37	Pongola				220			470	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
F139	27	23	31	37	SASA Experiment St.							394	
F140	27	23	31	37	Industrial sites				167			480	
F141	27	23	31	37	Pongola				250			450	
410/203	27	23	31	37	Pongola	17		154	92	160	5	414	
F142	27	25	31	37	Mvutshini				123			394	
F143	27	23	31	38	Pongola P54							500	
F144	27	22	31	39	Pongola P89							470	
F145	27	23	31	39	Pongola P20				177			369	
F146	27	22	31	40	Pongola P100				140			333	
F147	27	22	31	40	Pongola P105							450	
F148	27	23	31	43	Nqumite			163	100	66	1	340	
410/679	27	19	31	53	Golela	14		122	83	115	5	325	
709	27	19	31	54	Lavumisa		20	91	88	67		± 266	Swaziland
878	27	08	32	00	Ingwavuma	47	130	275	122	206	38	771	
W4 R01	27	25	32	04	Pongolapoort	11	69	109	163	82	50	473	Dam
412/052	27	22	32	32	Mseleni	48	18	31	181	134	3	367	
180	27	30	32	36	Mbazwane			36	396	197	8	637	
443/196	26	46	30	07	De Emigratie	21		45	24	22	3	94	
F149	26	36	30	29	Kliprug			121				220	
W5 R01	26	39	30	29	Jericho	74			107	56	51	214	Dam
W5 R03	26	43	30	33	Morgenstond	79			124	47	61	232	Dam
444/126	26	36	30	35	Athole	27		121	51	35	3	210	
F150	26	37	30	35	Athole			124				217	
F151	26	31	30	37	Westoe			150				275	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
444/203	26	53	30	37	Idalia	39		127	110	103		340+	
W5 R02	26	30	30	38	Westoe	49			182	73	36	291	Dam
444/277	26	37	30	40	Amsterdam	28	2	148	50	55	4	259	
F152	26	38	30	40	Amsterdam							274	
F153	26	38	30	40	Amsterdam							300	
F154	26	40	30	40	Sterkfontein		180					240	
F155	26	41	30	40	Sterkfontein			132				279	
F156	26	41	30	40	Sterkfontein			130				175	Too low
F157	26	31	30	41	Dingleside							± 300	
444/316	26	46	30	41	Wolwekop	40	3	132	78	63		276+	
F158	26	54	30	41	Idalia			127				356	
F159	26	31	30	44				150				256	
F160	26	35	30	44	De Hoop		150					293	
F161	26	56	30	44	Varkpan			151	141	98		390	
444/430	26	40	30	45	Roburnia State Forest	51		194	60	88	2	344	Also: F162
484	26	34	30	47	Nerston	40	14	190	54	37	2	297	
F163	27	00	30	48	Piet Retief		3	186	185	140	10	524	Also:408/512
F164	27	00	30	48	Piet Retief				303			528	
444/742	26	52	30	55	Houdkop	33	3	171	175	80		429	
837	26	57	30	58	Bothashoop	33	3	206	239	86	6	540	
445/100	26	40	31	04	Mankayane	-	244 (2 days)	134	44		422		Swaziland
274	26	32	31	10	Malkerns	-	186	125	13	2		326	Swaziland
512	26	32	31	18	Matsapha	-	22	230	85	16		353	Swaziland

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
445/788	26	38	31	27	San Roy	25	23	348	220	19	2	613	Swaziland
863	26	53	31	29	Kubutu	49	45	205	333	72		655	Swaziland
446/311	26	41	31	41	Siphofaneni	30		60	340	124		524	Swaziland
355	26	55	31	42	Poponyane	14			490	100		± 590	Swaziland
471	26	51	31	46	St Phillips		46	293	65	136		540	Swaziland
772	26	52	31	56	Big Bend		41	197	78	59	2	377	Swaziland
M	26	49	32	12								345	Mocambique
447/446	26	56	32	15	Ndumu	56	39	91	226	95	5	456	
M	26	46	32	23								281	Mocambique
M	26	52	32	52								103	Mocambique
480/170	26	20	30	06	Welgelegen	14		41	19			60	
347	26	17	30	12	Bothwell	6		44	18	5		67	
F165	26	28	30	22	Sandrift			100	100	42		242	
481/167	26	17	30	36	Busby	15	8	101	38	12	2	161	
239	26	29	30	38	Broadholm	35	3	190	48		2	243	
282	26	12	30	40		8		58	141	49		248	
853	26	13	30	59	Oshoek	31		228	83			311+	
482/260	26	20	31	09	Mbabane		45	393	52	17	3	510	Swaziland
344	26	14	31	12	Mbuluzi	22	45	335	72	17		469	Swaziland
357	26	27	31	12	Mc Creedy	46	31	216	89	19	3	358	Swaziland
867	26	27	31	29	St. Joseph Mission	117	26	177	159	50		412	Swaziland
483/042	26	12	31	32	Foyersbracla		30	264	88	1	21	404	Swaziland
053	26	23	31	32	Mpisi 1		280 (3 days)		76	81	437	Swaziland	
082	26	22	31	33	Dinedor	15	30	347	111	5	25	518	Swaziland

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
483/426	26	06	31	45	Swaziland Ranch Homeland	15	55	227	139	3	36	460	Swaziland
695	26	05	31	54	Vuvuland	28	36	232	126	45	65	504	Swaziland
729	26	09	31	55	Nokwane		95	215	100	67	2	479	Swaziland
807	26	27	31	57	Siteki (Mabuda)		68	352	217	30	2	669	Swaziland
M	26	12	32	08	Goba		97	201	72	60		430	Mocambique
M	26	29	32	11								740	Mocambique
M	26	14	32	12								463	Mocambique
M	26	03	32	20	Boane		100	90	32			222	Mocambique
M	26	19	32	21								321	Mocambique
517/072	25	42	30	03	Belfast	19		31	36	5		72	
X1 R01	25	57	30	05	Nooitgedacht	31		27	45	0	1	73	Dam
517/275	25	35	30	10	Elandsfontein	10		37	46		4	87	
578	25	38	30	20	Waterval	21		63	26			89	
762	25	42	30	26	Weltevreden	42	4	154	51			209	
816	25	36	30	28	Elandshoek	48		54	20	3	4	82	
518/088	25	28	30	33	Badplaas	3		84	37			121	
186	25	36	30	37	Vlakplaats	69	2	105	14	2		123	
197	25	47	30	37		9	3	131	28		4	166	
X1 R03	25	53	30	37	Vygeboom	79			118	28		146	Dam
518/346	25	46	30	42	Onverwacht	4	5	172	26		6	209	
367	25	37	30	43	Coetzeestroom	45		127	260	3		390	
393	25	33	30	44	Berlin	34		200	18	1	5	224	
455	25	35	30	46	Kaapsehoop	47		170	52	5		227	
F166	25	40	30	48	Snymansbult							150	
F167	25	40	30	50	Boschfontein				100			178	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
518/589	25	49	30	50	Nelshoogte	25		213	111	11		335	
F168	25	38	30	51	Maritzdrift							250	
F169	25	38	30	51	Rietbokspruit			152				185	
F170	25	45	30	51	Sweet Acres			200				360	
F171	25	43	30	56								250	
F172	25	47	30	56	Kempstone			± 100				± 200	
F173	25	47	30	57	Hopewell							268	
F174	25	38	30	58	Worchester Gold Mine			100				160	
518/859	25	49	30	59	Oorschot	4		292	64		14	370	
886	25	46	31	00	Carmichael	3	1	188	52		6	247	
F175	25	47	31	00	Barberton Prison			256+	34 +	4+		294+	
519/016	25	46	31	01		3	3	204	21		2	230	
F176	27	43	31	03	Barberton		400 (2 days)					445	
F177	27	43	31	03	Barberton			85				130	too low
519/077	25	47	31	03	Barberton	17		256	34			290+	
139	25	49	31	05		17	35	305	95		7	442	
448	25	58	31	15	Pigg's Peak		225	615	60	6		906	Swaziland
F178	25	33	31	18	Boulders Excelsior							245	
F179	25	33	31	18	Excelsior		130					230	
F180	25	33	31	18	Excelsior							175	
519/518	25	38	31	18	Louws Creek	12	81	242	15	5	12	295	
519/-	25	55	31	22	Peak Timbers		208	408	38	4		658	Swaziland
F181	25	32	31	24	Rockvale			130				156	
519/707	25	47	31	24	Ngonini		28	211	109			348	Swaziland
F182	25	37	31	27	AMO Bosbou							± 300	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
F183	25	44	31	29	Jeppe's Reef			135	35	17		187	
519/880	25	40	31	30	Buffelspruit	20		231	39	12	31	313	
F184	25	39	31	33	Lomati Land-goed							310	
F185	25	36	31	34	Laughing Waters							383	
F186	25	36	31	40	Hoechst		22	192	21	27		262	
520/387	25	37	31	43	Tunzini	6	45	189	70	25	56	385	
450	26	00	31	45	Mananga	16	47	250	130	11	15	453	
F187	25	36	31	46	Uitsig			180				300+	
520/476	25	56	31	46	Bordergate	15	58	197	149	12		416	
F188	25	37	31	47	Strydom Block			120				282	
F189	25	37	31	50	Adrian 439			132				226	
520/589	25	49	31	50	Fig Tree	17	54	160	52		33	299	
F190	25	37	31	51	Leeubos			225				356	
F191	25	31	31	52	Umkomaas							325	
F192	25	37	31	52	Sqwamans 416				208			275	
F193	25	34	31	54	Inyoni		52	196	75			323	
F194	25	31	31	55	The Harp Coopersdal			200				307	
F195	25	32	31	56	Coopersdal		71	112	47	30		297	
F196	25	37	31	56	Louisville			225				356	
M	25	58	32	00								295	Mocambique
M	25	58	32	35	*Maputo*		96	99	9	35		239	Mocambique
X2 R05	25	22	30	24	Braam Rauben-heim	102		3	50	18	2	73	Dam
554/885	25	15	30	30	Kaffervoetpad	76		150	12	6	3	171	
890	25	20	30	30	Kalmoesfontein	19	53	3	4	4	5	69	
555/030	25	30	30	31	Elandshoogte	47		174	21	3	6	204	

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP[2] 14 (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
555/280	25	10	30	40	Long Tom	37	3	81	12		3	99	
405	25	15	30	44	Brooklands	23	8	100	4	17		129	
437	25	17	30	45	Tweefontein	10		125	9	6		140	
441	25	21	30	45	Rietvallei	40		99	25		6	130	
455	25	05	30	46	Ceylon	13	2	49	3		2	56	
462	25	12	30	46	Waterval	31	12	106	5	18		141	
483	25	03	30	47	Tweefontein	21		43	6			49	
486	25	06	30	47	Sabie	22	48				7	55	
528	25	18	30	48		25		140	6	26		172	
548	25	08	30	49	Malieveld	12	10	99	10	20	3	142	
573	25	03	30	50	Klipkraal	27		5		38	5	48	
579	25	09	30	50	Spitskop	19	5	116	12	27		160	
631	25	01	30	52	Welkom	61		36	22	30		88	
662	25	02	30	53	Frankfort	47		48	13	18		79	
664	25	04	30	53	Bergvliet	65		73	5	12	0	90	
X2 R03	25	14	30	54	Witklip	16		112	12	2		126	Dam
555/792	25	12	30	57	Swartfontein	25		284	52	8		344	
837	25	27	30	58	Nelspruit	21	3	111	5	2		121	
878	25	08	31	00	Witwater	29		60	6		3	69	
X3 R01	25	09	31	01	Da Gama	29		1	69	5	6	81	Dam
556/020	25	20	31	01	Witrivier	21		106	22	12		140	
088	25	28	31	03	Mayfern	12	5	101	16	2	2	126	
110	25	20	31	04	Jatinga	13	12	105	14	7	2	140	
X2 R04	25	23	31	05	Primkop	30		18	99	1	2	120	Dam

No[1]	Rain Gauge Lat. °	'	Long. °	'	Place	AP_{14}[2] (mm)	Rainfall at 8 am January 29	30	31	February 1	2	Total[3] Rainfall PS (mm)	NOTES
556/183	25	03	31	07	De Rust	12	8	21	7	16	8	60	
679	25	19	31	23		13	8	140	1	16		165	
898	25	28	31	30	Malelane	8	67	106	4	11		188	
557/115	25	25	31	34	Riverside	10	24	128	9	16		177	
F197	25	24	31	42	Lodwichs Lust			135				239	
F198	25	29	31	46	Wilsonskop			150				289	
F199	25	23	31	49	Albert			200				350	
557/666	25	06	31	53	Lower Sabie Rest Camp	4	41	56		47		144	
F200	25	30	31	53	Rooigras							350	
557/712	25	22	31	54	Krokodilboug	7	85	118	17			220	
F201	25	23	31	54	Die Berg			176				299	
F202	25	26	31	57	Komatipoort							380	
F203	25	26	31	57	Komatipoort		127					293	
F204	25	26	31	57	Komatipoort							325	
557/806	25	26	31	57	Komatipoort	5	85	84	52	37		258	
F205	25	30	31	57	Grimman							327	
F206	25	30	31	57	Grimman							397	
F207	25	25	31	58	Komatipoort		60	170	94	42		366	
F208	25	29	31	59	Merribeek							± 450	

Notes (1) Weather Bureau stations: six-digit numbers
Departmental dams: gauging station numbers
Flood questionnaire data: 'F' followed by number

(2) AP_{14} = antecedent rainfall: The 14-day period before the storm

(3) Symbol + above number: Total rainfall was more than the number

APPENDIX 2: SUMMARY OF RAINFALL AND FLOOD DATA

SITE No	DRAINAGE REGION or STATION No.	GEOGRAPHIC POSITION Lat.	GEOGRAPHIC POSITION Long.	RIVER	PLACE (farm, road, bridge, dam)	METHOD OF FLOOD PEAK MEASUREMENT	CATCHMENT AREA A (km²)	FLOOD PEAK max gauge height (m)	FLOOD PEAK discharge Q (m³/s)	FLOOD PEAK return period T (yr)	FLOOD PEAK Kovacs K	FLOOD PEAK accuracy class	FLOOD PEAK date + time MDH	PREVIOUS MAX PEAK Qo (m³/s)	FLOOD VOLUME Ω (10⁶m³)	FLOOD VOLUME p (mm)	RAINFALL (mm) 28Jan - 2Feb (08h00) max point Pm	RAINFALL (mm) 28Jan - 2Feb (08h00) areal P̄	RAINFALL (mm) 3 day-200yr areal P̄ 200	RUN-OFF % P/F	REMARKS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	V3M05	27°26'	29°59'	Slang	Vlakdrift	G	676	6,53	400	20	3,43	2	01.31.20	240	73,1	108	275	250	280	43	(9) DT limit = 5,09 m
2	V3R01	27°57'	29°57'	Ngagane	Chelmsford	D	830	–	I: 84 θ: 0	< 10	1,98	1	01.31.03	140	13,0	15,7	85	80	260	20	
3	V3M10	28°04'	30°23'	Buffels	Tayside	SA	5887	7,09	1190	20	3,09	2	02.02.14*	870	550*	93,4*	340	175	230	53*	(9) DT limit = 2,74 m * overestimated /unreliable
4	V3	27°50'	30°32'	Spartelspruit	Rehlingen	SA	104	(1,93)	291	20-50	4,09	U	01.31	–			350	310	240		(10) Upstream farm dam broke
5	V3M11	27°54'	30°35'	Bloed	Bembaskop	B	543	5,39	1200	50	4,45	U	01.31.17	840	156	287	550	385	235	75	(9) DT limit = 0,83 m
6	W1R02	28°54'	31°27'	Mlalazi	Eshowe	D	14,3	0,44	I: 31,3 θ: 29	< 10	3,42	1	01.31.12	10	1,97	138	440	420	445	33	
									I:108 θ: 95	10	4,20	1	02.18.07		3,43	240		>500	445		Cyclone Imboa (19) inaccurate rainfall
7	W1R01	28°46'	31°29'	Mhlatuze	Goedertrouw	D	1273	–	I:1900 θ: 0	20-50	4,44	1	01.31.14		153	120	450	360	340	33	
									I:1290 θ: 0	20	4,10	1	02.18.12		54,1	42,5	500	220	340	19	Cyclone Imboa
8	W1M09	28°45'	31°45'	Mhlatuze	Riverview 11459	SA	1136*	6,67	2400*	20-50*	4,70*	2	01.31.18	2075	162*	143*	460*	370*	360	39*	)(9) DT limit = 3,34 m) * Data refer to catchment)d/s of dam W1R01
								4,30	1000*	~15	3,93*	2	02.18.12		76,3*	67,2*	600*	240*	360	28*	Cyclone Imboa
9	W1M05	28°34'	31°24'	Mfuluzone	Golden Reef	G	45	1,63	51,1	9	3,24	U	01.31.05	185	3,09	68,7	440	400	390	17	(9) DT limit = 2,16 m
								2,08	98,5	<20	3,69	1	02.18.11		5,32	118	190*	185*	390	64*	Cyclone Imboa *inaccurate
10	W2R01	27°51	30°49	White Umfolozi	Klipfontein	D	340	3,25	I: 1090 θ: 980	50	4,58	2 2	01.31.08		102	300	520	450	235	67	
11	W2M09	27°54'	30°53'	White Mfolozi	Doornhoek	SA	432	4,25	1050	≤ 50	4,45	2	01.31.10	274	81,6	189	520	480	235	39	(9) DT limit = 2,60 m
12	W2M05	28°20'	31°23'	White Mfolozi	Overvloed	SA	3939	7,40	7500	0,65RMF	5,18	2	01.31.13	2124			735	460	250		(9) DT limit = 1,30 m (15) July 1963
13	W2	28°24'	31°43'	White Mfolozi	Game Reserve	SA	4776	(8,1)	6500	50-200	4,94	2	01.31	3964			725	445	265		(15) Oct. 1957 at station W2M03 (A = 5136 km²)
14	W2M08	27°56'	31°12'	Black Mfolozi	Ekuhlengeni	SA	238	7,00	2180	0,65RMF	5,27	2	01.31.04	217			650	640	285		(9) DT limit = 1,85 m
15	W2M07	27°58'	31°12'	Bizamkulu	Ekuhlengeni	SA B	78 78	3,21 –	580 587	20 20	4,70 4,71	1 1	01.31.04 01.31.04	480			630 630	560 560	290		(9) DT limit = 1,06 m
16	W2	28°04'	31°33'	Black Mfolozi	Native Res. 12	SA	1635	(9,2)	7500	0,96RMF	5,56	2	01.31.01	2195			920	610	280		(9) DT limit = 1,52 m (15) July 1963 at station W2M06 (A = 1648 km²)
17	W2	28°16	31°51'	Black Mfolozi	Game Reserve	SA	3396	(9,4)	10000	0,93RMF	5,52	2	01.31.12	2832			920	580	285		(15) Oct. 1957 at station W2M02 (A = 3468 km²)
18	W2	28°27'	32°06'	Mfolozi	Native Res.5	SA	9216	(12,8)	16000 -	0,95RMF	5,55	2	01.31				920	500	305		

NOTES
Col 7 G = river gauging station D = dam S A = slope area B = bridge contraction
Col 10 I = inflow peak θ = outflow peak
Col 13 '1' = error less than ± 10% '2' = error less than ± 30% 'U' = unknown accuracy
Col. 9: figures in brackets indicate mean depth of main channel.

SITE No.	DRAINAGE REGION or STATION No.	GEOGRAPHIC POSITION Lat.	GEOGRAPHIC POSITION Long.	RIVER	PLACE (farm, road, bridge, dam)	METHOD OF FLOOD PEAK MEASUREMENT	CATCHMENT AREA A(km²)	FLOOD PEAK: max gauge height (m)	FLOOD PEAK: discharge Q (m³/s)	FLOOD PEAK: return period T(yr)	FLOOD PEAK: Rodier K	FLOOD PEAK: accuracy class	FLOOD PEAK: date + time MDH	PREVIOUS MAX. PEAK Qo (m³/s)	FLOOD VOLUME Ω (10⁶m³)	FLOOD VOLUME p (mm)	RAINFALL (mm) 28Jan-2Feb (08hoo) max. point Pm	RAINFALL (mm) 28Jan-2Feb (08hoo) areal P̄	RAINFALL (mm) 3day-200yr areal P̄ 200	RUN-OFF % P/P̄	REMARKS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
19	W2M10	28°27'	32°09'	Mfolozi	Native Res. 5	B	9248	–	15400	0,92RMF	5,51	2	01.31.20	8500			920	500	305		(9) DT limit = 4,50 m (15) July 1963, overestimated
20	W3	28°09'	32°01'	Hluhluwe	Game Reserve	SA	516	(6,1)	2050	≤ 50	4,92	2	01.31				520	445	425		
21	W3R01	28°07'	32°11'	Hluhluwe	Hluhluwe	D	734	3,08	I:2940 Θ:1800	50–200	5,07	2	01.31.10	3060	126	172	520	450	420	38	(15) July 1963
22	W3M01	27°41'	31°40'	Mkuze	Rietboklaagte	SA	1467	5,80	3100	< 50	4,81	2	01.31	3320			730	470	250		(9) DT limit = 5,48 m (15) July 1963
23	W3M02	27°36'	32°01'	Mkuze	Morgenstond	SA	2647	(7,2)	5500	50–200	5,06	2	01.31				730	480	270		(9) No DT
24	W4	27°19'	30°54'	Pongolo	Mooiplaats	B	1731	–	2750	50	4,62	2	01.31.10 01.31.17				800	480	230		
25	W4	27°35'	30°33'	Soetmelks	Geelhoutboom	SA	62	(2,7)	230	20–50	4,14	U	01.31.08				610	510	245		
26	W4	27°31'	30°49'	Bivane	Uitval	SA	878	(3,6)	855	20–50	3,93	2	01.30	1019			610	440	230		(15) July 1963 at station W4M04 (A = 948 km²)
						B	878	–	1060	20–50	4,12	2									
27	W4	27°18'	31°15'	Mozane	Tobolsk	SA	426	(5,0)	3020	0,70RMF	5,31	2	01.30.18				710	660	255		
28	W4M03	27°25'	31°31'	Pongolo	Grootdraai	G	5788	6,9	9200	0,67RMF	5,19	1	01.31	3404			800	630	230		(9) DT limit = 3,07 m (15) July 1963
29	W4	27°25'	31°38'	Pongolo	Mvutshini	SA	6110	(7,3)	9800	0,70RMF	5,23	1	01.31.01				800	625	230		(6) d/s of Rouilliard bridge
30	W4M06	27°22'	31°47	Pongolo	M'Hlati	SA	6846	13,2	11000	0,75RMF	5,30	1	01.31	2800			800	590	245		(9) DT limit = 2,16 m
31	W4	27°24'	31°50'	Pongolo	Sunland	SA	6955	(8,6)	11500	0,78RMF	5,34	1	01.31				800	590	245		
32	W4R01	27°25'	32°04'	Pongolo	Pongolapoort	D	7831	–	I:13000	0,83RMF	5,41	2	01.31.04		2105	269	800	570	265	47	(10) I was obtained from peaks surveyed at sites 28 – 31.
									Θ:1480				02.04								From dam-levels I = 16800 m³/s: overestimated. Θ: controlled
33	W4	27°06	32°04'	Ngwavuma	Mbuzini	SA	1660	(6,8)	4250	50–200	5,04	1	01.31				720	590	365		
34	W5	27°02'	30°45'	Assegaai	Welverdiend	SA	1652	(3,3)	500	≤ 10	3,10	2	01.31				400	265	255		
35	W5M06	27°07'	30°50'	Swartwater	Zwartwater	SA B	180 180	5,0	400 600	50	4,09 4,39	U 2	01.30	270			650	480	240		
36	W5M22	27°04'	31°00'	Assegai	Zandbank	SA	2313	5,9	1400	10–50	3,84	2	01.30	368			650	320	225		(9) DT limit = 7,00 m
37	W5	26°42'	31°26'	Mkondvo	Sidvokodvo	SA	3844	(7,1)	4900	50–200	4,77	2	01.30				710	420	310		
38	W5	26°44'	30°44'	Hlelo	Kromrivier	SA	732	(3,5)	300	< 10	3,14	2	01.31				360	210	205		

NOTES
Col. 7 : G = river gauging station D = dam S A = slope area B = bridge contraction
Col. 10 : I = inflow peak Θ = outflow peak
Col. 13 : '1' = error less than ± 10% '2' = error less than ± 30% 'U' = unknown accuracy
Col. 9: figures in brackets indicate mean depth of main channel.

SITE No.	DRAINAGE REGION or STATION No.	GEOGRAPHIC POSITION Lat.	GEOGRAPHIC POSITION Long.	RIVER	PLACE (farm, road, bridge, dam)	METHOD OF FLOOD PEAK MEASUREMENT	CATCHMENT AREA A (km²)	FLOOD PEAK max. gauge height (m)	FLOOD PEAK discharge Q (m³/s)	FLOOD PEAK return period T (yr)	FLOOD PEAK Rodier K	FLOOD PEAK accuracy class	FLOOD PEAK date + time MDH	PREVIOUS MAX. PEAK Qo (m³/s)	FLOOD VOLUME Ω (10⁶m³)	FLOOD VOLUME p (mm)	RAINFALL (mm) 28Jan - 2Feb.(08hoo) max. point Pm	RAINFALL (mm) 28Jan - 2Feb.(08hoo) areal P̄	RAINFALL (mm) 3day-200yr. areal P̄ 200	RUN-OFF % p/P̄	REMARKS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
39	W5M05	26°50'	30°44'	Hlelo	Ishlelo	G	804	1,88	256	10	2,95	1	01.31.22	709			360	210	205		(9) DT limit = 3,04 m
40	W5M04	26°45'	30°28'	Ngwempisi	Bushmanspruit	G	460	1,25	65,8	5	2,16	1	02.01.01	144	15,4	33,5	220	170	190	20	(9) DT limit = 1,82
41	W5R03	26°43'	30°33'	Ngwempisi	Morgenstond	D	546		I: 97	< 10	2,37	1	01.30.06		21,7	39,7	230	190	190	21	
42	W5R01	26°39'	30°29'	Mpama	Jericho	D	218		I: 65	<10	2,60	1	01.31.04		13,1	60,1	220	175	190	34	
43	W5M26	26°41'	30°42	Ngwempisi	Merriekloof	G	628*	2,97 •	409*	<20	3,49*	2	01.30.14	440	40,1*	63,8*	280	240*	190	27*	* Data refer to catchment d/s of dams W5R01 and W5R03 (9) DT limit = 1,5 m
44	W5M08	26°29'	30°38'	Bonnie Brook	Broadholms	G	119	1,36	43,5	6	2,64	1	01.30.11	178	4,44	37,3	250	210	210	18	(9) DT limit = 1,14 m
45	W5R02	26°30'	30°38'	Usutu	Westoe	D	531	–	I:180	<10	2,90	1	01.30.07		33,3	62,7	250	180	205	35	
46	W5M24	26°23'	30°51'	Mpuluzi	Dumbarton	SA	1446	3,87	509	10	3,20	2	01.30.11	140	84,0	58,1	310	240	230	24	(9) DT limit = 1,14 m
47	W5	26°38'	31°26'	Great Usutu	Sidvokodvo	SA	5170	(6,4)	4740	≥ 50	4,58	U	01.30				620	340	250		
48	W5	26°52'	31°55'	Great Usutu	Matata	SA	17974	(9,0)	11300	0,68RMF	4,80	2	01.31				700	460	300		
49	W	26°48'	32°28'	Maputo	Madubula	SA	31600	–	16000*	0,74RMF	4,87	U	01.31				800	500	290		* Obtained from DNA Mocambique
50	W6M01	26°10'	31°35'	Black Imbuluzi	Swaz GS3	G	723*	–	1673*	20–50	4,60	2	01.30.03*		140*	194	580	480	340	40	* Obtained from WRB Swaziland
51	W6	26°08'	31°41'	Black Imbuluzi	Mnjoli	D	851*	–	θ:1635*	20-50	4,50	2	01.30*								* Obtained from WRB Swaziland
52	W6	26°12'	32°08'	Umbeluzi	Goba, E10	G	3250*	9,78*	6150*	50-200	5,07	2	01.30.12* 01.31.10*		565*	174	610	495	360	35	* Obtained from DNA Mocambique (16,17,21): Storage in Mnjoli Dam (Swaziland) included
53	W6	26°03'	32°20'	Umbeluzi	Boane E8	G	5600*	11,00*	7250*	50-200	4,97	2	01.30.15* 31.13*		1050*	188	610	490	380	38	* Obtained from DNA Mocambique (16, 17, 21): storage in Mnjoli Dam (Swaziland) included
54A	X1M01	26°02'	31°00'	Komati	Hooggenoeg	G	5499	3,2	830	9	2,77	1	01.30.18	3416	89,3	16,2	355	175	210	9,3	(9) DT limit = 2,46 m (10) Obtained from site 54
54B	X1	26°02'	31°01'	Komati	Kromdraai	SA	5509	(3,4)	832	9	2,77	1	01.30				355	175	210	*	
55	X1	26°00'	31°36'	Komati	Iysis Weir	G	7330*		3630*	20–50	4,10	2	01.30.02*		502*	68,5	800	255	265	27	* Obtained from: Swaziland Irrigation Scheme via Chunnett, Fourie and Partners
56	X1	25°52'	31°49'	Komati	Trading Site	SA	8040	(7,4)	2640	20-50	3,70	2	01.31				800	285	260		
57	X1M03	25°41'	31°47'	Komati	Tonga	G	8614	2,71	2070	20-50	3,40	2	01.31.12	600	356*	41,3*	800	285	270	15*	(9) DT limit = 3,00 m * underestimated
58	X1	25°46'	31°26'	Mlumati	Horo	SA	642	(4,2)	1800	50	4,71	1	01.30				800	560	335		

NOTES
Col. 7 G = river gauging station D = dam S A = slope area B = bridge contraction
Col. 10 I = inflow peak θ = outflow peak
Col. 13 '1' = error less than ± 10% '2' = error less than ± 30% 'U' = unknown accuracy

Col. 9: figures in brackets indicate mean depth of main channel.

SITE No.	DRAINAGE REGION or STATION No.	GEOGRAPHIC POSITION Lat.	GEOGRAPHIC POSITION Long.	RIVER	PLACE (farm, road, bridge, dam)	METHOD OF FLOOD PEAK MEASUREMENT	CATCHMENT AREA A (km²)	FLOOD PEAK: max gauge height (m)	FLOOD PEAK: discharge Q (m³/s)	FLOOD PEAK: return period T (yr)	FLOOD PEAK: Rodier K	FLOOD PEAK: accuracy class	FLOOD PEAK: date + time MDH	PREVIOUS MAX PEAK Qo (m³/s)	FLOOD VOLUME Ω (10⁶m³)	FLOOD VOLUME p (mm)	RAINFALL (mm) 28Jan - 2Feb (08h00) max point Pm	RAINFALL (mm) 28Jan - 2Feb (08h00) areal P̄	RAINFALL (mm) 3day-200yr areal P̄ 200	RUN-OFF % P/F	REMARKS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
59	X1	25°41'	31°33'	Mlumati	Driekoppies	SA	940	(5,4)	2100	20–50	4,67	1	01.30.				800	480	370		
60	X1M14	25°41'	31°35'	Mlumati	Lomati	SA	1119	7,82	2150	20–50	4,61	1	01.30.06	349			800	465	370		(9) DT limit = 3,68 m
61	X1	25°29'	32°00'	Komati	Grimman	SA	10785	(6,8)	3100	20–50	3,68	2	01.30.22				800	310	345		
62	X1	25°29'	31°46'	Ngweti	Herculina	G	80*	–	θ: 150	< 20	3,73	2	01.30.08*				380	280	455		* Obtained from Haliboma Fibris Pty Limited
63	X2M15	25°29'	30°42'	Elands	Lindenau	G	1554	2,14	178	2,5	2,20	1	01.30.18	260	25,5	16,4	390	170	190	9,7	(9) DT limit = 2,46 m
64	X2M13	25°27'	30°43	Krokodil	Montrose	G	1518	1,14	59,8	< 2	1,24	1	01.30.13	188	11,4	7,5	205	92	230	8,2	(9) DT limit = 2,46 m
65	X2M29	25°28'	30°49'	Visspruit	Alkmaar	G	30	0,73	9,9	3	2,33	1	01.30.05	16,0	0,63	21,1	205	180	390	12	(9) DT limit = 2,16 m
66	X2M05	25°26'	30°58'	Nelspruit	Boschrand	G	642	0,67	11,1	< 2	0,46	1	01.30.21	61,0	2,42	3,8	150	130	335	2,9	(9) DT limit = 1,72 m
67	X2M06	25°28'	31°06'	Krokodil	Karino	G	5097	2,80	234	3	1,54	2	01.31.01	815	52,5	10,3	390	140	270	7,4	(9) DT limit = 1,72 m
68	X2M32	25°31'	31°14'	Krokodil	Weltevrede	G	5397	1,88	318	< 10	1,80	1	01.30.10	577	60,1	11,1	390	145	265	7,7	(9) DT limit = 5,18 m
69	X2M30	25°43'	30°47'	Suidkaap	Inloop	G	57	0,86	11,9	< 2	2,11	1	01.30.13	71,0	0,825	14,5	270	250	245	5,8	(9) DT limit = 1,24 m
70	X2M24	25°43'	30°50'	Suidkaap	Glenthorpe	G	80	1,03	17,4	< 2	2,19	1	01.30.16	82	1,14	14,3	310	260	240	5,5	(9) DT limit = 1,85 m
71	X2M31	25°44'	30°59'	Suidkaap	Bormans Drift	G	262	2,68	230	10	3,48	2	01.30.18	205	6,89	26,3	360	270	260	9,7	(9) DT limit = 1,70 m
72	X2M08	25°47'	30°56'	Queens	Sassenheim	G	180	2,12	212	20	3,61	2	01.30.16	125	10,8	60,0	360	270	260	22	(9) DT limit = 1,09 m
73	X2	25°44'	31°00'	Queens	Daisy Koppie	SA	320	(3,4)	700	20–50	4,26	2	01.30				375	360	285		
74	X2	25°44'	31°03'	Hyslop Creek	The Thorns	B	43,4	–	200	20–50	4,19	U	01.30				350	350	245		
75	X2M10	25°37'	30°53'	Noordkaap	Bellevue	G	126	1,66	48,8	2,5	2,69	1	01.30.18	200	2,47	19,6	200	180	290	11	(9) DT limit = 2,13 m
76	X2	25°41'	31°11'	Sheba	Sheba Station	SA	73,3	(2,0)	175	< 20	3,88	1	01.30				400	315	245		
77	X2M22	25°33'	31°19'	Kaap	Dolton	SA	1639	4,9*	1370	25	4,02	2	01.30	720			400	265	275		(9) DT limit = 0,9 m * u/s of blocked bridge opening
78	X2M37	25°25'	31°37	Krokodil	Riverside	SA	8479	3,5	1100	< 10	2,73	2	01.30				400	170	305		(2) Yet to be built
79	X2M17	25°26'	31°38'	Krokodil	Thankerton	G	8811	2,3	1320	10	2,90	2	01.30.18	722	163	18,5	400	170	305	11	(9) DT limit = 1,82 m
80	X2M18	25°17'	31°37'	Mbyamiti	Sku.-Mal.Drift	G	618	1,57	137	< 10	2,58	1	01.30	1082			180	145	330		(9) DT limit = 3,07 m

NOTES
Col. 7 G = river gauging station D = dam SA = slope area B = bridge contraction
Col. 10 I = inflow peak θ = outflow peak
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Col. 9: figures in brackets indicate mean depth of main channel.

SITE No.	DRAINAGE REGION or STATION No.	GEOGRAPHIC POSITION Lat.	GEOGRAPHIC POSITION Long.	RIVER	PLACE (farm, road, bridge, dam)	METHOD OF FLOOD PEAK MEASUREMENT	CATCHMENT AREA A (km^2)	FLOOD PEAK: max. gauge height (m)	FLOOD PEAK: discharge Q (m^3/s)	FLOOD PEAK: return period T (yr)	FLOOD PEAK: Rodier K	FLOOD PEAK: accuracy class	FLOOD PEAK: date + time MDH	PREVIOUS MAX. PEAK Qo (m^3/s)	FLOOD VOLUME Ω ($10^6 m^3$)	FLOOD VOLUME p (mm)	RAINFALL (mm) 28 Jan - 2 Feb (08h00): max. point Pm	RAINFALL (mm) 28 Jan - 2 Feb (08h00): areal $\bar{P}$	RAINFALL (mm) 3 day-200yr areal $\bar{P}$ 200	RUN-OFF % p/$\bar{P}$	REMARKS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
81	X2M16	25°22'	31°57'	Krokodil	Ten Bosch	SA	10365	5,25	1800	15	3,11	1	01.31.00	1400	163	15,7	400	175	305	9	(9) DT limit = 1,50 m
82	X2M36	25°26'	31°59'	Komati	Lebombo	SA	21480	7,2	4750	20-50	3,67	1	01.31				800	265	295		(5) Incorrectly named Krokodil (9) DT limit = 1,49 m
83	X(E23)	25°23'	32°00'	Incomati	Ressano Garcia	G	21490	8,47*	5230*	20-50	3,78	1	01.31.00*		899*	41,8	800	265	295	16	* Obtained from DNA Mocambique
84	X(E22)	25°34'	32°15'	Incomati	Moamba	G	22140	9,6*	5200*	20-50	3,75	1	01.31.07*		1077*	48,6	800	250	-	19	* Obtained from DNA Mocambique
85	X(E43)	25°02'	32°39'	Incomati	Magude	G	37600	8,7*	2200*	<20	2,24	1	02.02.12*		1067*	28,4	-	-	-		* Obtained from DNA Mocambique

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